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Lloyd's Register Technical Association

THE WORK OF THE SALVAGE ASSOCIATION

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GUEST LECTURE

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FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Hon. Sec. S. M. Wehrle
71 Fenchurch Street, London, EC3M 4BS

THE WORK OF THE SALVAGE ASSOCIATION

by C. A. SINCLAIR, C.ENG., F.R.I.N.A., F.I.MAR.E., F.C.M.S., M.S.N.A.M.E.

INTRODUCTION

I am very thankful for the opportunity to address you in relation to the working of the Salvage Association, this especially as both The Salvage Association and Lloyd's Register work to about the same interface in relation to Underwriters' interests, and further, that on many occasions your staff are involved in acting for Underwriters through the Association.

In considering how best to provide a subject of interest to staff generally it was decided that the first thing would be to delve just briefly into the history of matters as this does colour the whole operation, and then to go into more detail indicating the specific areas of co-operation which are of value.

One of my hobby horses throughout my whole career has been accepting the theory that if you know the other man's background and problems you are half way to meeting the problems. For this reason my presentation will show the Salvage Association's view of matters in the hope that this will promote a better understanding of our requirements and reasoning. There will of course be another side which will occur to you but if we both appreciate each other's point of view at least something has been accomplished.

HISTORICAL BACKGROUND

Looking first at the history of matters and going back, as you in your organisation do, to the Coffee house days the quote from a report written by Pepys in 1663 comes to mind when he says:

"To the coffee house, where I heard the best story of a cheat intended by a master of a ship, who had borrowed twice his money upon the bottomry, and as much more insured upon his ship and goods as they were worth, and then would have cast her away upon the coast of France and there left her, refusing any pilot which was offered to him; and so the Governor of the place took her and sent her over hither to find an Owner, and so the ship is come safe, and the goods and all; they all worth £500 and he had one way or another taken £3,000, her cargo, vessels of tar daubed over with butter instead of all butter."

These problems existed in Pepys' day but they still continued perhaps in an even more refined form so that in 1774 John Waskett wrote:

"The numberless instances daily occuring of very extraordinary and skillfulness negligence and error together with atrocious deceit and imposition in claiming stating and settling of losses, averages, salvage returns, etc."

He further wrote at a later date:

"Litigation is become so rife that there is a neccessity however strange it may appear for the almost daily attendance which may be observed especially in term time of no less than four or five attorneys at Lloyd's coffee house, what a degredation is this of mercantile character and ability even in a single branch of commerce."

Attempts to meet these conditions progressed over the years and in 1803 a new clause was introduced into insurance policies commonly known as "Mr. Augustine's clause" requiring a certificate of survey by two British merchants in cases of claims for partial loss by sea damage arising at foreign ports.

Because of the frequency of losses to vessels which were thought to be unseaworthy, Lloyd's Underwriters set up a classification register. This register listed vessels which had been surveyed and were considered to be in sound insurable condition. The Lloyd's Register of shipping is said to have been first established in 1760 and their register was issued bi-annually as a confidential document to Underwriters only. This document was in fact so confidential that a replacement copy could only be obtained upon receipt of the outdated copy in the possession of the Underwriter concerned. The necessary survey of ships for inclusion in this register was at the expense of Underwriters and the whole document and service was both for and by them. Owing to feelings of discontent amongst Owners as to the vessels included, Owners set up their own register about 1799, Owners themselves paying for the survey of the vessels for inclusion in this register.

The existence of the two registers continued and it was in 1833 that negotiations brought together the two books and the following year 1834 the books were merged and Lloyd's Register of British and Foreign Shipping came into formal existence.

Thus we have the merging of one register which had been set up to protect Underwriters interests and another which existed in order to enable Owners to obtain insurance on their vessels, the difference may appear to be small but it is quite real.

In other areas of the world similar loss conditions were causing concern and in 1828 Netherlands Underwriters were so concerned that a Bureau of Information for Underwriters was set up in Antwerp. The functions of this Bureau were broadly similar to those of the British Registers. It will be seen that in these early days Underwriters were struggling to divest themselves of un-acceptable risks and to this extent they were successful in arranging for ships to be properly surveyed and classified. They were able to divest themselves of the expense of bringing the vessels up to this standard, or of surveying them to see whether they were up to this standard by making it a condition of insurance that they were maintained in classification.

In spite of the improvements in this respect they continued to suffer through unscrupulous persons and through claims which were being made which were not in fact legitimate. By the year 1856 the litigation which was going on between Underwriters and Owners and merchants was getting worse than in the days quoted earlier, it was therefore thought that a body should be set up to control damage surveys and present Underwriters with sound technical and financial opinions upon which they could judge the merits, or de-merits, of alleged damage claims being presented. In 1856 a body then called "the Association for the Protection of Commercial Interests as regards shipwrecked and damaged property", was set up and this body became commonly known as "the Salvage Association". This was perhaps one of the first co-operative ventures between Lloyd's and the Insurance Companies. The founding members were Lloyd's plus five of the biggest Insurance Companies. This co-operation was brought about because it was not economic or practical for each Underwriter to appoint his own Surveyor to a casualty. There were also ship owners and merchants in the membership, and in fact the Royal Mail Steam Packet Company is noted to have contributed 10 guineas as founder members, whereas members of Lloyd's contributed 5 guineas each. Whilst the title describes fairly well the purposes of the Association it was further said to be set up to provide a means of ascertaining the cause of the undue increase of losses arising from damage to ships and cargoes and of

finding a remedy for such a state of things injurious alike to every fair trader whether merchant ship owner or Underwriter.

From the very beginning suspicious losses were investigated and attempts to settle Underwriters with unreasonable repair costs were effectively countered. In the first instance this was carried out by appointment of agents or specialist Surveyors on a part time basis in various ports who were directed as occasion required. Usually the agent appointed was, and is today, the Lloyd's agent in the particular place. In 1863 the rules were compiled for the conduct of the affairs of the Association and with modifications these formed the basis of a royal charter granted the following year. The Association took unto itself the motto "Quaerite Vera" which by interpretation is "Seek the Truth" and this has formed the basis of all our operations from that day forward.

STAFFING ARRANGEMENTS

In setting up the Association profit was not a motive and this continues today. Many other things have changed, the scope of the work carried out, and the type of work is changing with changing years, and the Rules and Charter have been modified from time to time as necessary. The Association has today some 29 world offices staffed by engineer and nautical Surveyors. The work involved includes not only damage surveys but also work of a loss preventative character. The day to day management of the Association is in the hands of a General Manager, the Chief Surveyor and their various deputies; however, it's affairs and operations are controlled by a Committee whose members are: five nominated by the Committee of Lloyd's, five by the Committee of the Institute of London Underwriters, five by Members of Lloyd's Underwriters' Association, and five elected by the Company Members of the Association. The Chairman of Lloyd's, the Chairman of the Institute of London Underwriters and the Chairman of Lloyd's Underwriters' Association are ex-officio members of the Committee. Many past and present members of The Salvage Association Committee have also served on the Committee of Lloyd's, the Institute of London Underwriters and Lloyd's Register of Shipping. The Chairman of Lloyd's Register of Shipping is also an honorary ex-officio member of the Association's Committee.

It will be noted that both Ship Owners and merchants have dropped out of the Association's membership, this took place at quite an early stage in the Association's history. In spite of the Underwriter interest the Association has maintained the principle throughout that it is it's function to provide sound technical and financial opinions in relation to any claim made leaving the decision about payment of the claim to those with knowledge of insurance policies generally and Underwriters claims adjusters or officers. Except where engaged on warranty work the Underwriters are called upon to pay the fee for the Association's services; this applies whether or not the Underwriter decides to meet the claim.

In order to provide Underwriters with the technical and financial opinions necessary the Association appoints Surveyors or experts in whatever area is necessary. Besides having Staff Surveyors strategically situated in repair areas throughout the world a panel of experts is available in almost every sphere of operations and this is widely drawn upon as occasion arises. Where the Association has no staff office it is usual for instructions relating to casualties to be passed through to Lloyd's agents in the area. In some areas Lloyd's agents have their own survey staff or in others they have a list of consultants whom they consider are well qualified and having sufficient integrity to be entrusted with the job in hand.

In fact the instructions to Lloyd's agents read as follows:

"In selecting a Surveyor for vessels and/or their machinery, where there is the exclusive resident officer of the London Salvage Association he should always be employed, if available; otherwise the Committee of Lloyd's would prefer, as a general rule, that the choice should fall upon the Surveyor to Lloyd's Register of Shipping whenever there is one stationed in the agency district (who will, in accordance with his instructions, sign as "Surveyor to Lloyd's Register"); the agent must bear in mind, however, that he is responsible for the selection of the Surveyor, whoever it may be."

From the foregoing it is clear that the appointment of a Surveyor in any particular area is the responsibility of the Lloyd's agent although a preference is expressed that Lloyd's Register should if possible be employed.

Before any Surveyor is sent abroad by the Salvage Association he will have accumulated considerable experience in the survey of damages, preparation of specifications, cost estimating and the answering of enquiries forwarded from Underwriters' Claims and Average Adjusters. His training will also include the acceptance of the fact that it is not his concern as to whether or not the Underwriters should pay a claim but rather that they should have a sound technical document upon which to base their decision. It is usual, where Surveyors are sent into areas where the Underwriters' Agents have been in the habit of employing local Surveyors, for our Surveyor to be instructed to advise and assist; thus the local Surveyor is also in attendance.

Having located the right man our next problem is to get him to the place of the casualty as quickly as possible. This can present many difficulties, the first of which is to see that he has suitable papers to enter the casualty area. For instance, it may not be possible to get a British Subject into a certain area because of political tensions, or it may be necessary to send him first to another area to pick up his visa. It is usual for our Staff Surveyors to keep their International Health Documents up to date and to this end an appropriate department sees that they are served with renewal notices. Even after obtaining all necessary visas the Surveyor may spend a considerable period trying to get into a prohibited zone or to obtain the necessary transport for the final leg of his trip to the vessel. Surveyors usually have to use their own initiative in the later stages of transport and it is rather a fortuity than a hardship if something as simple as a helicopter or boat is available.

Having arrived at the vessel, regardless of the casualty, the Surveyor cannot board without the Owners' consent, so it is quite useless proceeding thus far unless this matter has first been cleared. Having boarded he is unable to put in hand the performance of any work even if he sees this would effectively minimize the damage; this can be most frustrating at times especially where time is of the essence. However the Owner, or Salvor (if this is one with a contact), must place all work in hand. It is not unusual for a Surveyor to board a vessel stranded in some remote spot to see that she would not be particularly difficult to refloat but, because of her age and low value, to find that no salvor is interested in rendering the necessary service. Recently our Salvage Officer managed to proceed to such a casualty and reported that tugs from two salvage contractors had been to the site and left again without even carrying out a survey to what he considered a fairly simple salvage job. In this case the political state of the country where the vessel was lost probably played a part, but also both the tugs had valuable towing contracts so any salvage job would have had to be very remunerative to be interesting.

Understandably present Owners' Representatives tend to lean heavily upon the Surveyors for advice, because our experts are constantly dealing with damages, whereas the Owners' Representative is unlikely to be in this position. However, care is exercised to avoid formulating the Owners' claim for him.

MAJOR CASUALTIES

Today, in the case of major damages, it is unusual for the Surveyor to be presented for approval with a specification already drawn up by a competent Owners' representative, although in some cases the Owners do arrange for estimators from shipyards to write specifications. Thus, although it is not the Surveyor's function to prepare the damage specification, it frequently falls to his lot to do so because there is no one else present at the survey who is competent to do so. Some specifications are most difficult to prepare. This applies especially to the damages where much of the damaged property is completely destroyed. With some vessels Owners can provide complete details of the fitting and equipment from the new building details. This is not always possible with older ships.

We frequently find with the smaller Owners that the man engaged to negotiate with the Surveyor is either completely non-technical or else is a consultant who has been engaged in relation to the particular incident and thus has no knowledge of the vessel's operating experience or previous history. In these cases it is often found that at the time of survey no clear indications are available as to the Owner's basis of claims—either in part or fully—so the Surveyor of necessity reserves the right to express his opinions after the Owner's have put forward an official allegation.

It is quite remarkable in cases of machinery damage, how some Owners are unable to put forward an allegation until after they have received an opinion from the Average Adjusters' Consultant, who then alleges a clear case of, say, 'negligence'. Yet neither the crew nor the Owners' Consultant or Superintendent could see so clearly as to make the allegation at survey. It is difficult to see how the seagoing staff can be said to be negligent when the cause of damage is so obscure that the experts who see the damage are themselves unable to find any operational fault. In reviewing many of these cases it is clear that there is little documentation which could be said to constitute statements of fact and the proposed claims seem to constitute a statement based mainly upon opinion, probabilities and sometimes, at the most, possibilities.

When abroad, the Surveyor frequently finds that the man representing the Owners is wearing more than one cap—perhaps Classification, Shipyard or Underwriters, or even all together.

Where there is a clear case of damage, it may even be possible to perform all these functions satisfactorily, but where there is any element of doubt each function should be in the hands of a different person. In spite of this, it is quite remarkable how successfully some well known characters in distant parts have combined all the said functions for very many years—to their own entire satisfaction!

Frequently with major casualties, the normal repair costs in an area are no longer relevant and the Surveyor finds that the number of firms interested in effecting repairs is quite limited. This interest can depend upon commitment and changes constantly. In times past, if a vessel had been involved in a casualty everyone appeared to be prepared to assist, at a price; however, to-day where a vessel has been so involved if she is outside territorial waters, it is frequently difficult to obtain permission to enter same and, with the Owners, the Surveyor becomes involved in discussions with Government officials who are constantly being harassed by bodies concerned in the possibility of pollution. These difficulties are even greater with tankers, and other vessels likely to leak oil, and it is not unusual for the authorities to insist that the vessel be rendered safe and perhaps gas free before entry. The difficulties in this respect are even greater when it is desired to bring the casualty into port. In this case, not only are safety and pollution problems involved but many harbour masters are reluctant to allow a lame duck to tie up part of their commercial facilities for an extended period.

Where Owners are claiming a Constructive Total Loss the Surveyors are frequently confronted with an Owner's desire to minimize the amount spent in proving his claim, and frequently this makes assessment difficult of the true extent of damage. The claim is then put forward with very extensive areas of assumed damage, and either estimates or tenders taken to substantiate the loss. When vessels are in a repair area the Surveyors can reasonably request that opening up be effected to an extent where any assumptions made can be proved to be beyond reasonable doubt, but in remote areas this is hardly possible.

SOME DIFFICULTIES ENCOUNTERED

I suppose one of the most disturbing types of cases to both Surveyors and Underwriters are those where a vessel is accepted as a C.T.L. and having been purchased on an "as is where is" basis is later repaired and put back into service at a very much lower figure. This state of affairs is beyond the control of the Surveyor; firstly, because it may well be possible to repair the vessel to satisfactory trading condition without removing all the damage, and, secondly, he may have had to concede—usually in later correspondence—that possible further damages were not as serious as claimed.

Another serious disadvantage suffered with casualties away from the main centres relates to communications both for the Surveyor and the Owners for both are frequently deprived of the opportunity of considering the vessel's history, due to the lack of suitable records being kept on board. At times, the Surveyor is faced with what appears to be a one-off type of incident and concedes it could have been incurred as alleged; however, if he had the complete case history of the vessel he would have suspected some other dominant cause.

Because of the conditions under which vessels are insured, the responsibility of disclosure of information lies with the Owner and the Surveyor is normally provided with all the casualty information which he considers pertinent. This includes such records as may be necessary to satisfy him as to the reasonableness of the allegations. Where, due to weather, loading, the vessel's commitments or other such factors, an incomplete or unsatisfactory survey is carried out, the Surveyor informs Underwriters to this effect and it is general for a further survey to be requested under more favourable circumstances.

Where a survey is carried out by persons other than Staff Surveyors, a system of instructions has been evolved whereby the survey requirements are spelt out in some detail to the Surveyor. This becomes especially necessary in cases involving General Average, collisions, or the like.

We stress to all Surveyors and consultants that it is essential that they keep detailed notes of their intervention as one of the difficulties encountered during adjustments is the inability of other people to answer questions when, for some reason or another, the Surveyor concerned is no longer available.

Sometimes language problems can cause difficulties and misunderstandings between Surveyors and Owners. However, when engaged on salvage operations, these difficulties can account for much frustration, especially on cases where

the operation is extended and several nationalities are involved. Whilst on this subject, the instruction books, name tags, log books, etc., are frequently a cause of concern, especially on old tonnage in remote corners of the world and it is quite frequently found that the crew cannot understand the documents and at times they may even be in more than one language.

I suppose the challenges of new types of vessels, larger vessels, more sophisticated machinery, and of course smaller crews are being met by all sections of the insurance industry, but the stamina of the Surveyor or his basic training do little to help him meet these and the sheer physical size of vessels is, in fact, turning the surveying field into one for the younger man.

Many of the special purpose vessels present rather unique problems in the event of serious casualties. For instance, large bulk carriers, O.B.O.'s and container vessels have no cargo handling gear, so if the vessel strands in some remote place the question of discharge or jettison of cargo becomes a very difficult one involving time finding suitable gear and erecting same before any discharge can be performed. Quite recently, one such vessel became a C.T.L. when, had there been cargo gear on board, there would have been sufficient time to jettison the 12,000 tons necessary for floatation before a storm made the casualty an uneconomic salvage/repair possibility. Of course, in other instances there has been sufficient time and discharge has been effected, but the damage to the vessel usually increases with each day. Whereas at one time with oil tankers and other vessels, if necessary to obtain floatation, the Surveyors or Salvage Officers would recommend jettisoning oil—reasoning that it was better to accept a limited outflow than to risk the total outflow if a vessel broke up—today Surveyors and all working on ship salvage are prevented from accepting this course by the stringent anti-pollution laws enforceable in most parts of the world.

In fact, because of a combination of the anti-pollution laws and the great increase in operational costs, it is now becoming most difficult to interest salvors in rendering service to large vessels on a Lloyd's Open Form basis.

The repair of large vessels has also changed the whole repair concept to one of repair by replacement, or in the case of hull work, the renewal of large prefabricated sections. The older Surveyor has great difficulty in accepting that a repairable component must be renewed, or that, say, 100 tons of steel must be replaced when only 90 are actually damaged, but modern repair facilities are only geared to work in this way. This has been largely brought about by the spiraling cost of labour and the decrease in availability of skilled personnel.

Developments have also meant a change in the skills of seagoing personnel to the point where most of their functions are taken over by automatic processes, and it is doubtful whether they will now react to emergencies in the same ways as previously. For this reason, it may well be that where negligence is alleged, the Surveyor, when he investigates, is unable to find any evidence to support this charge, so Owners may be faced with the fact that the prime cause is an automation failure and not a marine peril.

THE FUTURE

New challenges are now being faced by the Surveyors who move into another world when dealing with oil rigs, pipe lines and nuclear plant. These engineering disciplines are very different from the normal marine or power house engineering, although the basic engineering may be the same. We now face movements of oil rigs, concrete structure of large dimensions, pipe laying, sub-sea assemblies and mineral recoveries, and whilst these surveys are being carried out by our staff and Consultant Surveyors, and there is already a vast amount of know-how existing in the organization, we are currently building up a special department, geared to send specialists into any world areas to cope with problems when and as they arise.

These new developments are going to be most important because of the huge projects currently under way in the search for new energy sources, new supplies of minerals and the threatening effects upon world food supplies by the world population increases.

We have become accustomed to the huge sums involved in V.L.C.C. and other giant vessels, but the sums involved in the new industries are even greater, and so too will be the claims made upon the insurance industry. For these reasons we feel assured that the services we are about to provide will be not only well used but beneficial to this industry.

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Lloyd's Register Technical Association

Discussion

on

Mr. C. A. Sinclair's Paper

THE WORK OF THE SALVAGE ASSOCIATION

Paper No. 1 Session 1980-81

Hon. Sec. S. M. Wehrle
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Discussion on Mr. C. A. Sinclair's Paper

THE WORK OF THE SALVAGE ASSOCIATION

CONTRIBUTIONS

From Mr. B. Rapo:

In the opening paragraph of the paper, the Author refers to the interface between the work of the Salvage Association and that of L.R. Recently, we have handled the towage of a replacement dock gate: a structure of about 25 m × 15 m. Having been acquainted with the voyage profile, the structural capability of the dock gate was established, and other considerations relevant to ocean towage dealt with. A few months later, the issue of a certificate of fitness to be towed was authorised, but the Builders were advised by the Underwriters also to approach the Salvage Association for the same service.

I wonder if the Author is aware of similar instances, and I would be obliged if he would care to comment as to whether he would describe this case as representative of the interface between the Salvage Association and the Society, or should one perhaps refer to it as duplication of effort? Is it possible that a situation may arise where both organisations are equally keen to provide a particular service and so would find themselves in friendly competition with one another?

From Mr. N. A. Dawson:

It is always good to have a paper from sources other than our own technical association and your interesting contribution has been no exception.

There are, however, two questions I would like to ask, both of which have on very numerable occasions caused me some worry.

My first question concerns the estimated cost of repairs which Underwriters usually require along with the preliminary telex from the Surveyor notifying the extent of damage.

The ability to correctly estimate costs require either:

1) The experience gained after many months or even years in a particular repair port doing damage surveys, or alternatively,

2) A copy of the Repairer's price list.

The first could be difficult for L.R. Surveyors to achieve and as price lists are often closely guarded documents the second alternative also presents some difficulty.

Incorrect estimates do of course lead to embarrassment when the final accounts are verified and in view of this I would appreciate any guidance you can give on the matter? Does the Salvage Association have its own specimen price lists or guidance notes to Surveyors on this subject?

The second point I would raise concerns damage specifications. I personally have never had to prepare one other than for a minor damage and I would suggest that if possible a more comprehensive specimen could be included in the written discussion.

On page 4 of the paper "Lloyd's Open Form" is mentioned. This appears to be a misprint and should be "Lloyd's Standard Form". Could Mr. Sinclair comment on this and also confirm that the basis of this contract is *No Cure No Pay*?

From Mr. W. C. Goodall:

Mr. Sinclair should be complimented upon the many and varied aspects of the work of the Salvage Association in his paper. I feel a week's seminar would be inadequate, and yet he has managed to produce a document which I am sure will enlighten the inexperienced and generate discussion and questions among our more experienced colleagues. I for one welcome the opportunity of having Mr. Sinclair at our meeting and hope that with his expertise some of the questions which have arisen during my own surveys and in conversation with Outport Surveyors may be resolved.

Firstly, I and many others would be interested to know what happens to the preliminary advices and reports after they have been forwarded by the Lloyd's Agents. Usually the Surveyor hears no more until he receives an enquiry from the Average Adjuster some considerable time after the Survey has been completed. As I recall, 5 to 6 years was not uncommon, and sometimes on cases which appear on the surface to be of a minor nature. Could Mr. Sinclair throw any light on the reasons for these delays?

Mention has been made that the Association's Officers, before being despatched to foreign climes, have accumulated considerable experience in, among other things, damage surveys and estimates. With regard to damage surveys, our old favourite heavy weather is usually to the fore amongst the alleged causes. It is recognised that the effect of various bouts of heavy weather may be cumulative and lead to eventual failure and as different Underwriters may be involved it is incumbent upon the Surveyor to assess the contribution each of these periods of heavy weather has made to the damage under review so that the necessary division of liability may be made.

Mr. Sedgwick referred to this problem of heavy weather in the paper he read to this Association in the 1965-66 Session in which he intimated that, in the absence of anything to the contrary, it is usually assumed that the vessel was in sound condition at the last drydocking, or Classification Survey, whichever was the most recent.

However a lot of water has flowed through ruptured shell plates since 1965, for example, the period between actual drydockings has been increased. Bearing this in mind, could Mr. Sinclair say if there has been any change of thinking in relation to heavy weather damages and also the advice given to the Association's Officers for dealing with cases such as these?

On occasions, an Association Officer will attend a survey being carried out by an appointed Surveyor. Could Mr. Sinclair give us some idea of the deciding factors which determine this action and in such a case who would normally be responsible for compiling the report?

Finally, with reference to modern repair technique, I suppose I fall into the category of the older Surveyor who kept the repairs to a minimum provided they were in accordance with good repair practice and were acceptable to the Classification Society. It is readily understood that the block or fabricated section of repair would be beneficial to the Owner, albeit by the use of more steel than is actually required, since this would result in a quicker turn round of the ship; especially if the section is already fabricated on the ship's arrival at the repair yard. However, it has always been my understanding that Underwriters were not concerned with the time taken to effect repairs unless a 'Loss of Earnings Policy' was involved.

Would a Surveyor on reporting such a case be expected to mention the costs which would be involved in this type of repair with the estimated costs for a piece repair so that any adjustments could be made later?

From Mr. T. Lindsay:

Mr. Sinclair has skilfully presented us with a lot of information in small bulk. He has emphasised that his Surveyors are in action on many fronts.

I note that, in addition to being competent, a Salvage Association Surveyor must have other skills, for example, cost estimating, being a diplomat, and a mediator. This obviously calls for a very special type of man in an industry of high capital outlay and repair costs.

I would like to ask Mr. Sinclair two questions.

Firstly, under the heading *major casualties.* When abroad, the Salvage Association Surveyor frequently finds that the Owner's Representative is wearing more than one hat. This is a very interesting situation and perhaps Mr. Sinclair would like to expand on it?

Secondly, where the number of firms interested in effecting a repair is limited and I assume at least two or three tenders are called for, which party nominates the Repairer? Does the Repairer have to be acceptable to the Salvage Association?

Finally, I would like to associate myself with the thanks already extended to Mr. Sinclair for his paper.

AUTHOR'S REPLY

To Mr. Rapo:

Mr. Rapo mentions the interface which arose in the matter of towage approval. This interface can occur and there can be areas of duplication of effort but because of the specialisation in the practical aspects of towing in this organisation it becomes difficult to see a way out. It is, however, very helpful if it is known at an early enough stage so that there can be good co-operation and avoidance of unnecessary clashes.

To Mr. Dawson:

In reply to Mr. Dawson's questions relating to the estimated cost of repairs, the first requirement is that we as surveyors understand the reason for the need of this early figure. Once we understand the reason it then becomes less difficult for us to accept the necessity.

Firstly, it should be understood that insurance renewals do not fall due at the same time, they occur throughout the year, and at any time an owner may be negotiating for renewal in relation to his ship or fleet.

The Underwriter in arriving at a satisfactory premium level considers the whole history of the Owner, his fleet or vessel, and so it is important to the Underwriter that he has an idea of any outstanding claims. It is incumbent upon the Owner to disclose any relevant information he will be seeking to minimise this in order to get the most favourable rate possible. It is not true to say that the Underwriter wishes to maximise the rate but he does wish to know from some independent person the liabilities he is likely to have accumulated over the policy period.

The next matter relates to Underwriters liabilities generally. In fact, they are required to be able to show that they have not accepted risks in excess of their financial resources. An Underwriter's day to day business is accepting risks and he needs to know his outstandings in order to keep completely up-to-date and within the law.

The above-mentioned estimates do not require to be formed with great accuracy. If, during the course of repairs, the work is found to be more or less extensive or some other factor enters consideration, the Surveyor is perfectly at liberty to send a revised estimate indicating his reasons. This is in no way considered to be a reflection of the Surveyor's ability; it is well understood that there will be times when changes are justified.

Another case where estimates are required, this time with a fair degree of accuracy, relates to cases where the damage sustained is not repaired at the time of survey. This is because the costs may escalate or they may decrease according to where and when the ship is ultimately repaired, but the Owners are benefitting by continuing to trade the vessel. The Underwriters may on their part decide that compensation should be on the basis of the cost of repairs in the first possible repair port.

Mr. Dawson mentions the difficulty in estimating until several years of experience have been attained. The point is taken that the young surveyor will have difficulties. I think in this regard that the assistance of his senior colleagues is of great help. Copies of Repairer's price lists, as mentioned, are very valuable and an attempt should be made to obtain them. The use of the lists still requires a fair degree of experience because the wording is generally of necessity rather short and the Surveyor needs to know by experience what is included or what items will form extras to the repair prices listed.

A further question is whether the Salvage Association has price lists. No, it is not our practice to carry extensive lists although our Information Retrieval Service is able to provide considerable help upon request, especially as to the cost of parts. We do, however, publish annually comparative worldwide costs so that a man moving from one area to another should be able to fairly quickly assess the possible cost differences on a percentage basis from those experienced in the area in which he is working. These figures are published annually in Lloyd's List but, of course, are available from us also upon request.

Mr. Dawson raises the further matter as to whether a specimen specification can be included for the written contribution; a copy of a specification relating to various work on a V.L.C.C. is included in Appendix I. In writing any specification, the point to bear in mind is, as each item is written down in concept it then becomes necessary to look closely at the item and see it is fully described in order that no unexpected extras arise during the work period and therefore in the account. Skill in specification writing can avoid many unexpected situations arising at the end of the repair; as with the Ship Repairer, if the specification has been badly written, he will probably neither have been allocated sufficient materials or labour for that particular aspect of the job and these extra items are likely to be charged for at premium rates.

The final point; it was an error to use the term "Open Form" in the paper, since this should have been "Lloyd's Standard Form". This is a no cure no pay contract. It is interesting to note that the term "Open-Form" was used to describe a situation where there was a space in the form

which could be filled in making a fixed lump sum, no cure, no pay contract, but if this were not filled in the form remained open. This is the origin but the form itself was and still is "Lloyd's Standard Form". It is of further interest to note that the Salvage Association was the body which collated the necessary information and set in motion the formation of the first ever Lloyd's Standard Form.

To Mr. Goodall:

Mr. Goodall enquires what happens to the preliminary advices and reports after they have been forwarded to the Salvage Association by Lloyd's Agents. Upon arrival at the Salvage Association they are examined to see that they comply with the brief given to us and by us in the instructions, that is that they cover the points that have been requested and make reasonable sense, both technically and insurance-wise. If the case appears to be straight-forward, a copy of the report is handed to the broker who provides same to the Owners who in turn feed this and all relevant documentation to the Average Adjuster. The Average Adjuster on his part examines the documentation in relation to the policy conditions for the vessel to see that the Owner has a legitimate claim and that this is properly quantified. This is the stage at which most enquiries are made.

In the event that the answers of the Surveyor satisfy the Adjuster it is probable that he will just proceed with the adjustment. If the Adjuster is not satisfied he will in all probability provide a consultant with documentation on the case and request his opinion. After getting this opinion the Adjuster will probably again consult the Surveyor and see whether agreement can or has been reached. The Surveyor on his part should not look at this as being a reflection upon him or his ability. It is quite probable that the Adjuster has documentation and information which was not provided to him at the time of survey. It is further probable that the consultant will likewise have the advantage from a documentation point of view.

The point should be borne in mind that regardless of what documentation there has been, it is the Surveyor who actually saw the job so it is important that his opinion be carried.

Where reports coming in from the field contain items which may be contentious or at least in disagreement with the Owner's allegations, it may well be that these reports do not go to the Broker and from the Broker to the Average Adjuster. This also applies to the confidential letters which go in that event to the leading Underwriter. The Adjuster will then make out his adjustment on the basis of the documentation provided by the Owner without the benefit of the Surveyor's report. In the final analysis the Underwriters' Claims Department will obtain the Surveyors report compare and consider this alongside the documentation provided by the Owners and Adjusters and decide upon this basis what is to be done about the claim.

Mention was made of the fact that sometimes Adjusters' enquiries are made even five and six years after a casualty; this is generally true because of difficulties encountered in Owners' and other offices accumulating the necessary documentation.

The question asked about the heavy weather apportionment over various voyages is quite interesting. It is a subject which could form the whole basis of a meeting. It may be said, however, that the heavy weather on various voyages is generally apportioned on a points system and points do need to be relevant to the type of failure. For instance, in a case of pounding damage one would expect to have entries in the log book as to pounding; in a case of racing, causing damage to machinery, one would expect to find some references to racing.

The writer has in fact himself evolved a points system which he uses and has used for many years, but it is by no means infallible; it is full of assumptions; it is just the best that he managed to evolve; Average Adjusters tend to do the same. They form a points system and judge accordingly, but in the end no matter what is done we are bound to be influenced by human factors. One man will describe as severe where another would call it mild, one will say very heavy where another would say heavy, and there will be changes of masters and crews during the currency of the vessel's life. It therefore becomes quite impossible to judge one man's entries against another.

Where entries do give cause for concern it is of course possible to check with the Meteorological Officer in various countries to find out the recorded conditions at that time, in the particular area, though even this may not be rewarding.

The reference to Mr. Sedgwick's statement in which he said "in the absence of anything to the contrary it is usually assumed the vessel was in sound condition at the last dry docking or classification survey, whichever was the most recent". It must be stressed that it would be in the absence of anything to the contrary.

The question, as to whether the Association decides to appoint a staff surveyor or even a consultant or to leave it entirely in the hands of a local surveyor, is interesting in that the answer is less easy to provide than the question. If the case is of major magnitude or contentious then it is considered prudent for us to appoint somebody who is accustomed to handling jobs of this type or size. It is also felt that if the case will involve discussion and argument such that the Classification Surveyor will have difficulty in wearing two caps then we would also try to send somebody to the casualty; access, transportation and time factors all being relevant. At other times Underwriters may for reasons best known to themselves request that the case be handled by a Staff Surveyor.

The Surveyor, having arrived on the scene, will be responsible himself for compiling a report, which means the Surveyor we send has also the benefit of the report of the local Surveyor. We do not take the case out of the hands of the local Surveyor when we send our man—he is there to advise and assist, and hopefully their reports will be in agreement.

The question with regard to "block repair" practice really comes back to the fundamentals. The Surveyor is instructed to ascertain in how far whatever is being done is fair and reasonable. Where the work is considered to be outside these parameters, he would then be expected to say what would have been fair and reasonable and what the difference in cost is.

Whilst accepting that except under special circumstances Underwriters are not concerned with the actual speed of repair, every day the vessel is under repair he is accumulating certain charges and, of course, these will be offset against any additional cost incurred by the method of repair or overtime working. It must be borne in mind, that if shipyards are not prepared to do a piece-meal repair, it is no use a surveyor saying it could have cost the Owner less by effecting repairs by this method—all these matters come into the fair and reasonable aspect.

To Mr. Lindsay:

Mr. Lindsay raises the matter of wearing several hats. This has, of course, been the cause of quite a bit of concern in various areas. On the other hand, because of the volume and work in those areas it is probably unavoidable. I do recall within the last couple of years getting a report

from a Surveyor in which he says the Classification Surveyor considers certain things, and then he outlines his own opinions. Now, in fact, they were both the same person; he was acting factually for Lloyd's Register in the one case and for us in the other. He was, of course, a consultant—he was a non-exclusive surveyor. I think these sort of incidents are diminishing and in fact in that particular area an exclusive surveyor has been appointed.

The next question relates to tenders. It must be emphasised that the Surveyor does not call for tenders; he may tell the Owner that he considers a prudent owner would do this, but he himself does not. He may also suggest to the Owner which parties could be invited to the tender having a better knowledge of the area than is likely with, for example, a 'tramp' owner. The Surveyor not only does not call for tenders, neither does he nominate the Repairer, this is the Owner's prerogative. He will hopefully be allowed to sit down with the Repairer and go through the tenders and be in agreement with what the Owner decides.

Further the Repairer does not have to be acceptable to the Salvage Association. However, if he is not acceptable, then there could be certain problems for the Owner in relation to the settlement of claims. We have said that the Surveyor should recommend that a prudent owner would call for tenders if the magnitude of the job warrants same, but it must be stressed that it is not the Surveyor's job to interpret policy conditions. There may well be a tender clause in the policy, but the Underwriter reserves to himself the right to invoke that clause and does not delegate that authority to anyone else. Where this clause is invoked, the Underwriter accepts certain other liabilities which he may in fact wish to avoid.

APPENDIX I

IMAGINARY REPAIR SPECIFICATION

The vessel is assumed to be of the V.L.C.C. type and to be at the yard in a gas and fire free condition in order to carry out any type of repair.

PART 'A'—Steel Repairs

1. BOTTOM SHELL REPAIRS

The following work to be carried out:

1.1 Plating (of Lloyd's Register of Shipping A.H. 7 Quality) In Way of Starboard Tank Nos. 1 and 2.

I-strake (double shaped plating) (counted from forward)

No. 5 plate to be renewed

(8000 × 2525 × 23mm) = 3717 kgs.

No. 6 plate to be renewed

(7950 × 2725 × 23mm) = 3986 kgs.

H-strake (double shaped plate)

No. 2 plate to be cropped and partly renewed, approximately half length

(4100 × 1925 × 21mm) = 1326 kgs.

G-strake (double shaped plate)

No. 3 plate to be renewed

(8100 × 2350 × 22.5mm) = 3426 kgs.

All above plating to be grit blasted to remove mill scale, marked, cut to size; butts and seams bevelled and double shaped.

1.2 Internal Structure

After cutting and removing of above plates, each side of standing internals in way to be treated for rewelding to new plating by flushing and burning off remains of welds and plating, chipping clean lower edges of internals, fairing lower edges of internals, viz.

a) I-strake plate No. 6 — 49 metres
b) I-strake plate No. 5 — 43 metres
c) G-strake plate No. 3 — 41 metres
d) H-strake plate No. 2 — 18 metres

Longitudinal No. 23 from frame 108 up till 108¾ to be cropped and part renewed incl. making 10 limber holes, each 200 × 100mm.

(3300 × 300 × 16mm F. H. Quality) = 127 kgs.

Web frame No. 113 lower part between longitudinal frame 17 and 18 to be cut, faired in workshop, refitted and welded.

= 112 kgs.

1.3 Bilge Keel Renewals

Shaped forward end of bilge keel to be renewed over 24 metres, forward end sniped as per drawing.

Flat bar to shell to be renewed over 7 metres, forward end sniped as per drawing.

a) Bilge keel (2400 × 550 × 20mm) = 2112 kgs.
b) Face flat (2200 × 80 × 20mm) = 282 kgs.
c) Shell flat (7000 × 100 × 15mm) = 84 kgs.

1.4 Miscellaneous

Worklights to be installed in 2 wing tanks and under vessel's bottom plating in way of repairs, attended during repairs, disconnected and removed on completion of repairs.

Outside shell plating to be hose tested in way of renewed plating.

During undocking inside or renewed plating to be checked.

Local manual cleaning to be carried out in scattered bottom areas, prior and during burning out of plates as required by safety regulations.

Ventilation: Electrical driven fans with necessary hoses to be fitted.

Ventilation equipment to be attended during repairs, equipment disconnected and removed on completion.

Cargo tanks (2) to be cleaned after repairs.

Cross bulkhead between starboard wing tank nos. 1 and 2 to be hose tested, incl. draining and drying tank after hose testing.

Staging columns each 10 ft. high with 2 work floors between each to be erected and removed, 32 metres in way of bilge keels and 30 metres in way of plate seams.

X-ray photos to be made of welding seams at 10 locations.

Coating

Grit blasting of renewed plating to be carried out and 2 primer coats of Owner's paint to be applied.

Photographs of damage to be made (10 prints).

Firewatchmen

Yards' fire hoses to be ranged from fire main into wing tanks and on completion of repairs disconnected and removed.

As required by safety regulations fire watchmen to be in attendance in starboard wing tanks nos. 1 and 2 during burning and welding (allow 300 man hours).

Bottom Shell Starboard Bilge Strake and Adjacent Bottom Plating

500 m^2 scored areas to spotblasted to SA $2\frac{1}{2}$.

2. **PORT SIDE SHELL REPAIRS IN WAY OF FORECASTLE STORE ROOM SPACE AND FOREPEAK TANK.**

The following work to be carried out:

2.1 **Shell Plating (shaped).**

One plate to be renewed between vertical frames nos. 123/124 and nos. 135/136 and horizontal frames.

Nos. 51/52 and just above watertight flat on horizontal frame No. 55 i.e. to original seams and butts. (approximately 8500 × 3000 × 23mm).

2.2 **Watertight Flat on Horizontal Frame No. 55.**

Stringer plating outside of solid pillars to be renewed from frames Nos. 129/130 to frames nos. 135/136, approximately 3 metres from shell plating (in four plates, each approximately 5000 × 1500 × 10mm).

2.3 **Internals in Forepeak**

Nos. 52, 53 and 54 longitudinal shell frames to be renewed over a length of approximately 8.3 metres (bulb flat bar 254 × 13mm).

Wash bulkhead on frame no. 128 to be cropped and partly renewed in two sections, approximate sizes are one at 3 metres and one at 2 metres × 600 × 10mm.

Transverse on frame no. 132 to be cropped and partly renewed in two sections; approximate size one at 3 metres and one at $2\frac{1}{2}$ metres × 450 × 10mm.

Two deck stiffeners each to be renewed over a length of 10 metres (178 × 10mm).

2.4 **Internals on Watertight Flat**

Two brackets with face bar to be renewed at lower parts about $1/1\frac{1}{2}$ metres high.

Brackets (600 × 125mm).

Face bars (100 × 25mm).

2.5 **Firewatch Services**

To be provided during repairs.

2.6 **For Access**

All stores to be removed by crew prior to vessel's arrival at repair yard.

Forepeak to be cleaned and certified for hot work before arrival at repair yard.

Store room racks and fittings to be removed and replaced (allow 400 man hours).

Stagings inside and outside to be erected and dismantled on completion of repairs (two tiers each 10 metres long externally and 50 metres of internal staging).

Temporary lighting and ventilation to be supplied during the repairs and removed again on completion.

Access openings to be cut in forepeak tanktop plating and reclosed on completion.

All repairs to be hydrostatically tested to Classification requirements.

One coat of shipyard supplied primer paint to be applied to new and disturbed work.

PART 'B'—Machinery Repairs.

1. **STEAM TURBINE PLANT**

Stal-Laval Type—Cross Compound Impulse
—S.H.P. Nominal 32,000±

The following work to be carried out:

a) **L.P. Turbine**

Turbine to be opened up and top casing removed clear.

Flexible coupling between L.P. turbine rotor and first pinion to be disconnected.

Bearing and thrust clearances to be adjusted and recorded. Labyrinth packings to be dismantled, cleaned and refitted.

Thermometers and pressure gauges to be disconnected and afterwards refitted.

Turbine rotor to be lifted, transported to shop, cleaned, calibrated and checked for truth.

All blade grooves on previously removed third (3rd) ahead stage in turbine rotor to be dressed up.

Third stage of rotor to be rebladed using Owners' supplied new blading.

In total 204 new blades to be fitted.

Turbine rotor to be dynamically balanced and returned to vessel.

New diaphragms, supplied by Owners, to be fitted to third stage casings.

All parts to be reassembled in good order to satisfaction of Owners' representative. Readings of all clearances and backlash of flexible coupling teeth to be taken and handed to Owners' representative.

Disturbed and damaged insulation on steam pipes and casings to be renewed.

Sea trials of four hours duration to be carried out and repairs proved to satisfaction of Owners' representative.

b) **Flexible Couplings**

Two (2) thermocouples to be disconnected, after repair cables reclipped, couples replaced, fitted and tested.

Flexible couplings of L.P. and H.P. turbines to be opened up for inspection, cleaned, backlash of teeth checked, axial clearances taken, results recorded. Couplings to be reclosed in good order.

c) **Main Boiler: Babcock & Wilcox Marine Radiant Type Primary Superheater**

Sixty-two (62) in number elements to be cropped and removed, together with all element securing brackets/supports on middle and circulating walls.

The landings of top and bottom headers for primary superheater to be polished and edges prepared.

Sixty-two new elements supplied by Owner to be shaped, installed, aligned and welded to respective top and bottom headers.

Note: All above welds to be carried out by boiler makers who are approved by the Classification Society.

Securing brackets and supports for new elements on middle and circulating water wall to be renewed, 186 in number.

Damaged refractory in superheater space to be renewed together with 14 in number stainless steel 'Y' anchors (allow for 1000 kgs of refractory material).

Miscellaneous and Access Work for Boiler Work Only.

Removal and replacement as original of casings and insulation in way of repairs to be effected.

Boiler to be cleaned before and recleaned after repairs.

Staging to be erected and dismantled.

Boiler to be tested hydrostatically and under steam to Classification and Owners' requirements.

d) **Main Condenser**

Four inspection covers to be disconnected and removed.

After cleaning, condenser covers to be refitted with jointing materials.

Covers, waterboxes and tubes washed down by means of H.P. waterjet.

e) **Atmospheric Condenser**

Six inspection covers to be disconnected and removed.

Two end covers to be disconnected and one cover removed.

Condenser covers, waterboxes and tubes to be cleaned and washed down by means of H.P. waterjet.

On completion covers to be refitted with new jointing materials.

f) **Main Lubricating Oil Coolers**

Two end covers of each lub. oil cooler to be disconnected and removed.

Both lub. oil coolers to be cleaned and washed down by means of H.P. waterjet.

On completion covers to be refitted with new jointing materials.

One pipe section 10″ × 1000mm and one pipe section 1″ × 1000mm off and on for access.

2. PROPELLER AND TAILSHAFT WORK

Tailshaft to be drawn and refitted with removals and refittings of pipelines to intermediate shaft bearings, coupling guards, cross over platform, tachometer, slipring bushes and rope guard.

Stern tube and shaft to be cleaned for inspection and magnaflux test of shaft carried out.

Cleaning and trueing up coupling bolts in situ.

Checking tailshaft weardown on completion.

Worklights, stagings, chainfalls and required heavy hoisting equipment to be provided and later removed on completion of work.

Shaft tunnel bilge to be dried by vacuum truck and cleaned as required for hot work in shaft alley.

Additional removals and replacements because of transport of inner seal and inner stern tube bush to be effected viz.

—floorplates to be disconnected and removed, floorplate supports to be cut and afterwards refitted and welded.

—24 metres railing to be removed and refitted, one filter to be disconnected, removed and refitted, miscellaneous pipe lines to be removed and refitted (allow 25 metres of $1\frac{1}{2}''$ copper pipe).

Hatch cover of engine room to be removed for transporting parts out and into engine room and later refitted.

Three plugs in propeller to be removed in order to fit hydraulic equipment and later refitted.

Shaft to be calibrated and sketches made indicating dimensions.

Stern tube bushes to be ultrasonically tested and results reported.

Outer seal to be completely disconnected, transported to workshop and afterwards new seal refitted in good order.

Inner seal to be completely disconnected, transported through engine room, and new Owners' supplied seal from workshop to be transported into engine room and fitted in good order.

Outer stern tube bush to be disconnected. Pulling equipment and hydraulic pumps to be rigged, outer bush pumped out and lowered into drydock.

Outer bush to be transported to and from workshop.

Inner stern tube bush to be disconnected. Pulling equipment and hydraulic pumps to be rigged, inner bush to be pumped out, transported by chain blocks under skylight area, hoisted out of engine room, transported to and from workshop and lowered into engine room to aft peak bulkhead after workshop repairs. Thermo-elements to be removed for access and later refitted.

After removal of bushes, stern tube to be fully cleaned for inspection and prior refitting of bushes.

Alignment check to be made with Taylor Hobson equipment and results reported.

Outer bush to be taken from dock floor, equipment rigged and bush pumped in, refitted and secured and drawing equipment removed.

Inner bush to be handled into place, equipment fitted, bush pumped into stern tube and drawing equipment removed.

Holding down bolt holes (6) of intermediate shaft bearing to be reamed, incl. alignment check of intermediate shaft, six new bolts to be made and fitted.

Nine coupling bolts and nuts to be transported to workshop, threads cleaned and bolts returned and refitted.

Shaft jacking tests to be carried out.

Taper contact test to be performed prior to permanent fitting of the propeller.

Stern Tube Bushes

Spare Owners' supplied outer bush to be set in caroussel lathe and outside diameter finish machined according to measurements taken.

Damaged outer bush to be calibrated and protocols made.

Spare outer bush after machining to be transported to milling machine, set up, 4 keyways marked and machined, 16 key stud holes drilled and threaded.

Spare Owners' supplied inner bush to be finish machined outside, incl. machining keyways etc.

Miscellaneous (Tailshaft)

Firewatchman to be in attendance (including portable extinguishers) during hot work removals and refittings for tailshaft work.

Area in engine room in way of tailshaft repairs to be cleaned during and after repairs.

3. MISCELLANEOUS AND ACCESS WORK RELEVANT TO ALL ENGINE, BOILER AND SHAFT REPAIRS

All dirt and debris connected with repairs to be collected and disposed of.

Engine room to be cleaned in way of repairs during and after repairs.

4. SEACHESTS, GRIDS AND SEA VALVES

In total 14 conventional bolted type gratings to be disconnected, removed for access and afterwards refitted and resecured.

Nine (9) seachests (six being over 25 m³ contents each) including gratings to be hardscrapped, H.P. washed and preserve painted twice.

Stagings to be erected and dismantled.

Sea valves to be opened, cleaned, inspected, spotted in, recoated, repacked and reclosed in good order with new joints viz:

Globe valves one—2″
one—3½″
one—10½″
Gate valves one—3″
two—4″
one—4½″
two—5″
one—6½″

Incl. transmission rods off and on.

Butterfly valves to be disconnected, removed, cleaned for inspection and refitted in good order, viz:

two—16″
one—28″
one—40″

PART 'C'—General Expenses

V.L.C.C. Type:

130,000 Grt	LPP 347.51 metres
290,000 DWT	B (Mld.) 51.90 metres
	D (Mld.) 51.82 metres

Vessel to be docked and undocked incl. first day of drydock dues.

Fourteen following days of drydock dues to be charged.

Vessel to be assisted with two tugs during shifting from river into drydock, including use of hawsers.

Vessel to be shifted out of drydock and into river with assistance of 4 tugs, pilot and boatmen, including use of hawsers.

During shifting to drydock, services of 2 deckhands and from drydock to repair quay in total 8 deckhands to be provided.

Two compressors to be installed on deck and compressed air system coupled up to the forward and aft winch.

Hereto one pipe section 3″ × 1500mm and one pipe section 5″ × 100mm of aft winch and one pipe section 8″ and one pipe section 10″ of forward winch compressed air and hire of compressors.

On completion, compressors to be transported ashore.

Vessel to be checked by chemist each day during repair period and certificates duly endorsed.

Electric Current

Cable leads to be connected to vessel's main switchboard and removed prior to undocking.

Approximately 45,000 kWh electric current to be supplied.

Earth cable connections to be made in drydock and removed on completion.

Cooling Water

Cooling water connection to be made, afterwards same removed.

Cooling water to be supplied whilst in drydock.

Fireguards and Appliances

Dock's fireline to be connected up to ship's system and afterwards removed.

Fire connection to be kept under pressure during repair period. Pressure to be adequate to operate fire hose on uppermost deck.

Twenty-four hour/day safety guard attendance on board.

Galley Refuse

Galley refuse to be disposed of daily during repair period.

Gangway

Two gangway and boarding towers to be arranged and removed during docking period and one gangway and boarding tower to be arranged and removed while vessel berthed alongside.

Service Air

Air vessel inclusive of required airhoses to be transported on board, rigged and via yard's compressed air system. Compressed air for ship's use to be supplied during repair period.

On completion all connections to be disconnected and removed.

Sixty eight heating appliances complete with infra red bulbs and cables to be transported on board, fitted and installed near generators and motors.

After repairs, the same to be removed and transported ashore.

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Lloyd's Register Technical Association

THE STRENGTH OF MARINE PROPELLER BLADES

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Paper No. 2. Session 1980-81

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THE STRENGTH OF MARINE PROPELLER BLADES

by J. S. CARLTON

SUMMARY

This paper explores the recent advances which have been made in the understanding of the factors influencing propeller blade strength. Consideration is given to both the aspects of stress analysis and material properties.

In addition to examining the characteristics of conventional propeller forms certain of the aspects relevant to the strength of ducted, controllable pitch and skewed propeller blades are considered. The environmental influences relating to blade strength are also mentioned.

Techniques for the measurement of propeller blade stresses are discussed including the new underwater telemetry method developed by the Society. The correlation between full scale results and calculation procedures is also indicated.

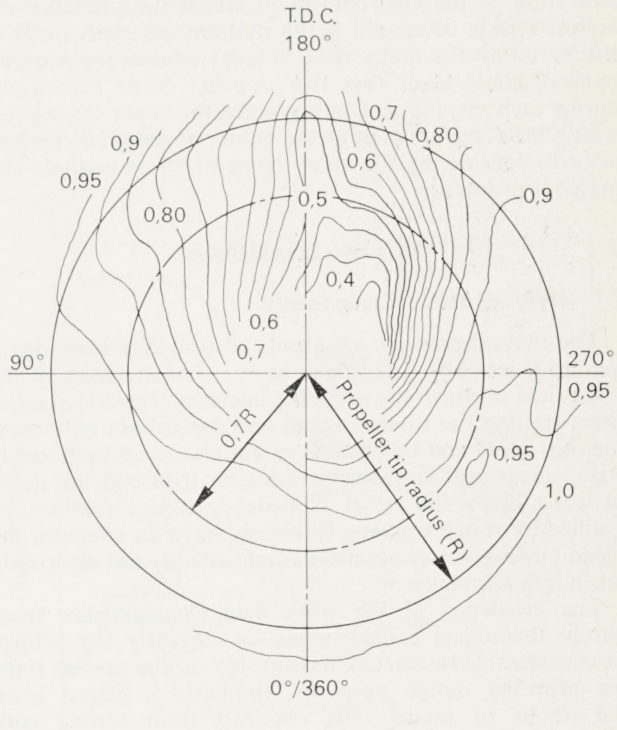
1 INTRODUCTION

Very nearly half a century has elapsed since the last technical paper (1) devoted to the subject of marine propellers was presented to this Association. In common with all other branches of technology, the intervening years have seen considerable advances in the understanding of all aspects of this subject. These advances, which to some extent rely on the ability to undertake complex analytical procedures, naturally owe much to the development of the digital computer. However, it is interesting and perhaps also a little comforting, to note that the basic calculation procedures that were developed some twenty or thirty years ago are still widely used as the basis for the design of most types of propeller.

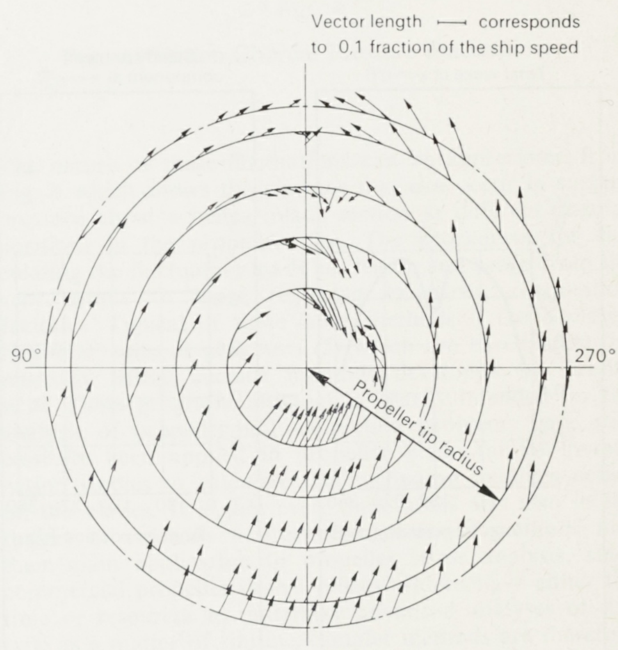
Although the propeller normally lies well submerged out of sight and therefore to some extent also out of mind, it is a deceptively complex component in both the hydrodynamic and structural sense. Indeed, often one finds that the hydrodynamic, strength and manufacturing requirements for a particular design are in direct conflict, thereby necessitating some degree of compromise between these opposing constraints—as such it is the attainment of this compromise which typifies the essence of good propeller design.

The subject of propeller strength, the foundations of which were laid in the early years of this century, examines the two complementary aspects of propeller stress analysis and the relationship of these stresses to the properties of the materials from which the propeller is manufactured. Both of these aspects are worthy of individual attention in their own right and indeed it was originally the intention that this paper should be devoted solely to blade stress analysis. However, such a treatment would of necessity be incomplete and the text was expanded to include a review of the behaviour and properties of the principal propeller materials.

Prior to the rapid increase in ship powering which occurred during the mid 1950's the incidence of blade failures had not been a major problem, since such failures as did occur could be easily explained in the light of the then present knowledge. However, the small but nevertheless significant proportion of failures which began to emerge from about that time served to underline the lack of appreciation and understanding of the fluctuating forces which acted on the propeller, and the influence that these forces had on fatigue life of the material of manufacture. In response to that situation extensive international re-



Contours of equal axial velocity components V_x/V



Velocity vectors in plane of propeller

FIG. 1

Typical Model Wake Field Definition.

search has been undertaken, and it is those aspects of this research which have contributed to the general understanding of the subject of propeller strength that form the basis of this paper. Consequenty, rather than break new ground, the ensuing discussion seeks to draw the various facets of the subject together in one document.

An appreciation of the problems underlying propeller blade strength cannot be gained without first giving consideration to the environment in which the propeller operates. This is because it is the environment, principally in the form of the wake field, which induces the variable hydrodynamic loads that the propeller blade experiences during each revolution. Consequently, the paper commences with a brief examination of the nature of the blade loading prior to considering the main theme of stress analysis and material properties.

2 BLADE LOADINGS

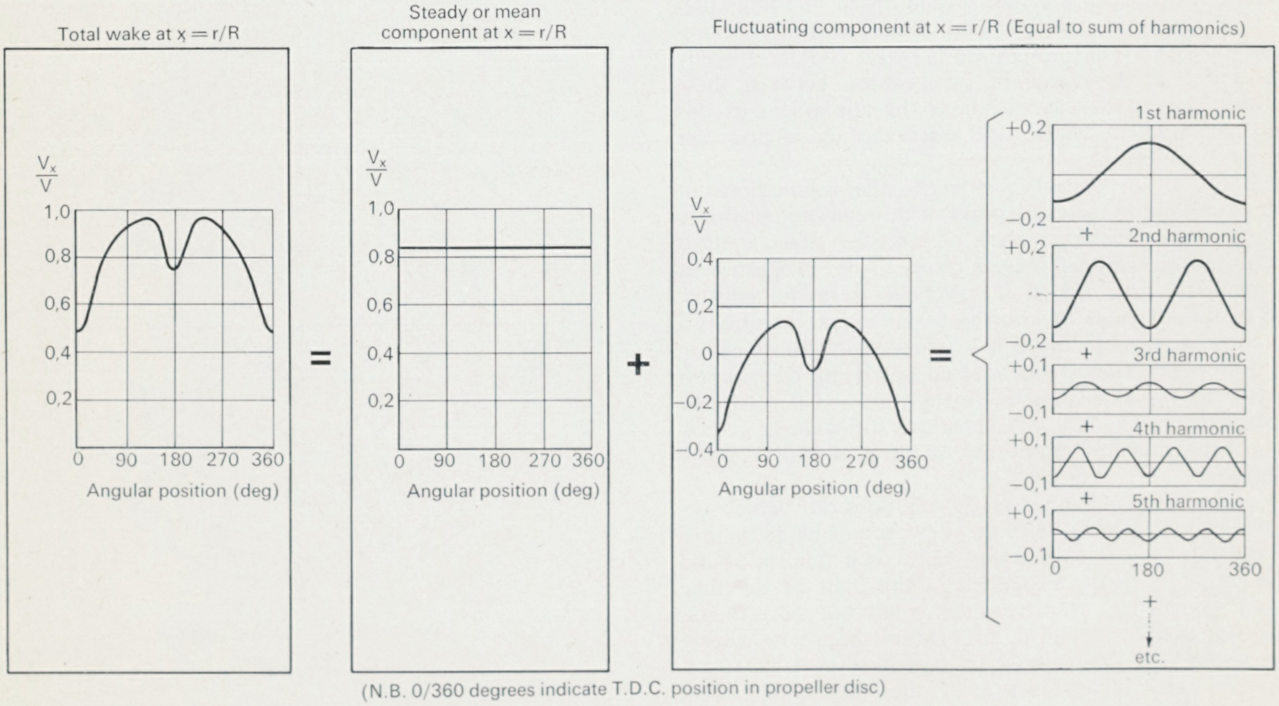
2.1 Hydrodynamic Components

The hydrodynamic components of propeller blade loading are principally determined by the characteristics of the wake field in which the propeller operates. These characteristics are peculiar to each vessel and depend not only upon the ship speed and hull geometry but also upon such steady state operational variables as draught, trim and the depth of water below the vessel. Non-steady state conditions, as typified by rough weather, obviously have an effect on the blade loading but as yet these conditions are not rigorously taken into account.

The prediction of the wake field characteristics from purely theoretical considerations is currently the subject of considerable research. Consequently, at the present time, for propeller design purposes, emphasis is placed upon the results of model tests obtained from towing tank studies. A typical specification of a wake field that would be obtained from towing tank measurements in this case relating to a twin screw ferry, is shown in Fig. 1. From these diagrams a complete description in terms of the speed and direction of the water entering the propeller disc at any point can be obtained, although in practice only the axial and tangential velocity components tend to be used due to the mathematical problems involved in dealing with the radial components. Indeed some wake surveys record only the axial velocity components since these are the major variation. However, this practice is not to be recommended since the tangential components have a small but nevertheless important influence, especially where cavitation considerations are involved.

Since the ship and model are run at different Reynolds' Numbers their boundary layers have different relative thicknesses. Therefore, if model wake data exists, it is clearly desirable to attempt a conversion of this information into its equivalent full scale form, the methods of Sasajima and Hoekstra being the most commonly used for this purpose. Unfortunately, these methods are largely unsubstantiated by direct ship model correlation due to the problems experienced when undertaking full scale wake measurements. Nevertheless, their use has been shown to improve the correlation of those other parameters that can be more readily measured and which are directly attributable to the wake field.

In order to determine the blade loadings the wake field is decomposed into both steady and fluctuating components, this separation being undertaken at each radial station where calculations are to be made. For many calculation purposes, especially where the more advanced forms of hydrodynamic analysis are involved, the fluctuating component is further split into its constituent harmonics. This process of wake field decomposition is shown schematically by Fig. 2 in which the axial wake distribution at a given radial station for a single screw vessel is considered. When considering these model wake fields in terms of their constituent harmonics it is important, if erroneous results are to be avoided, to appreciate the experimental accuracy of this data. Normally therefore, only the first eight or so harmonics are considered.



(N.B. 0/360 degrees indicate T.D.C. position in propeller disc)

FIG. 2

Decomposition of Wake Field into Mean and Fluctuating Components.

Whilst the use of model testing is becoming more widespread to determine the wake and other characteristics considered desirable in the ship design process, by no means are all vessels designed with the benefit of this information. In such cases a standard radial mean wake distribution, whose volumetric mean is equal to the mean wake obtained for resistance and propulsion considerations, is employed. The standard distributions of Van Lammeren and Harveld are amongst the most commonly employed for this purpose. Unfortunately no such established techniques exist for the estimation of the fluctuating wake components and recourse has to be made to either the recently emergent statistically based methods or to the many empirical guidelines, the basis of which are discussed in reference (2). In either event only limited information becomes available.

The mean loading distribution acting on a propeller blade is calculated from the inflow considerations dictated by the mean wake at each radial station and a wide variety of calculation techniques is available for this purpose. However, experience has shown that in the majority of practical applications the simpler analysis methods are perfectly adequate for this task. Typically the methods of Burrill (3) and Van Oossenen (4) fulfil the necessary requirements for this type of calculation, although in the case of the former method, which has the advantage of greater simplicity at the expense of theoretical rigour, use should be made of the more recently deduced hydrodynamic factors. The actual choice of method must naturally depend upon the propeller under analysis and it will be seen that the method of reference (4) is of a rather more advanced form and, therefore, would normally be applied to propellers having the more onerous duty. Nevertheless, the final choice of method should always reflect the accuracy of the input data and especially that of the wake field. The application of these methods result in the determination of the radial distributions of mean hydrodynamic blade loading, typical examples of which are shown for a conventional propeller by Fig. 3.

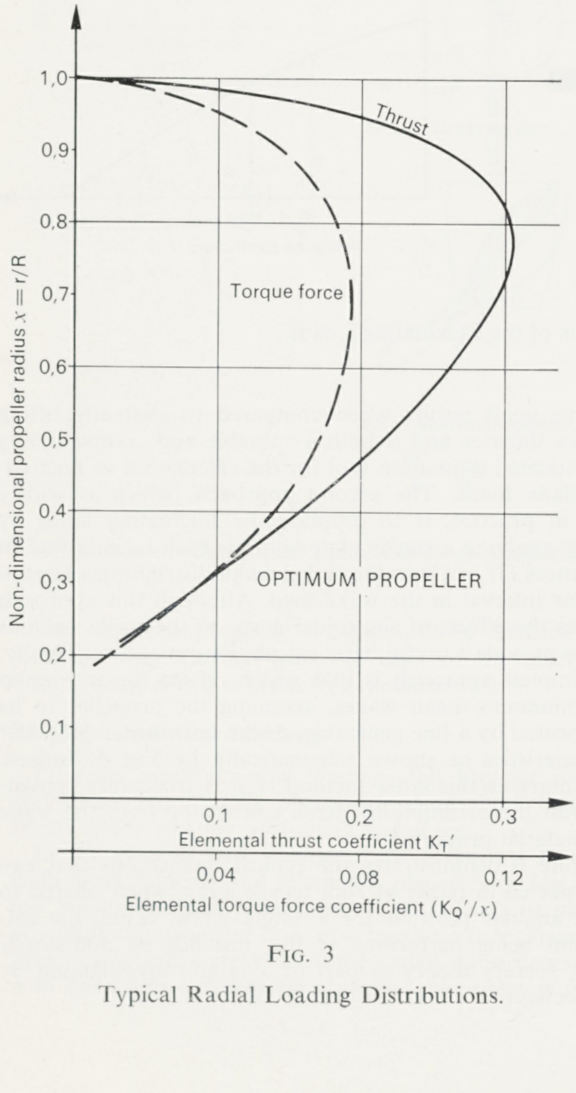


FIG. 3

Typical Radial Loading Distributions.

The harmonic components of the wake give rise to a fluctuating pressure field over the surfaces of the blades.

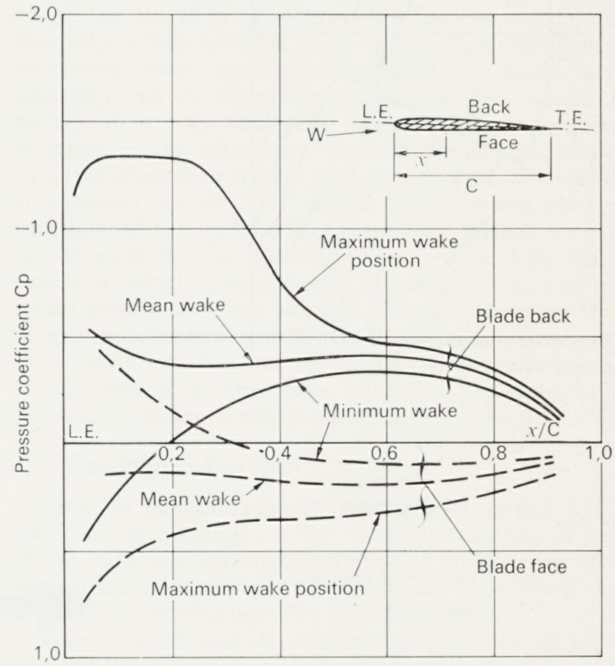


FIG. 4

Typical Section Chordal Pressure Fluctuations.

The nature of these fluctuations can be appreciated from Fig. 4 which shows the changes that can occur in surface pressure about a helical blade section at different angular positions in the propeller disc. The procedures for calculating the fluctuating loads are legion and range from the very simple to those requiring extensive computation facilities. Typical of these latter methods is the Society's HSPROP suite of programs (5) which are based upon the unsteady lifting surface methods developed by Breslin et al. These programs although primarily intended for the analysis of propeller-hull interaction problems have successfully been applied in propeller blade failure investigation studies to calculate the fluctuating loadings acting on the blades. It is, however, these areas and also in the realms of research where these advanced methods find their main application to propeller stress analysis, since commercial propeller design offices seldom have either the time or resources to undertake advanced analyses of this type as a matter of routine. Simpler methods are therefore sought and these range from 'advanced' quasi-steady analyses through to very simple estimation techniques. Three such methods serve to illustrate the type of calculation procedures in current use, these being outlined in descending order of complexity. The method of Sasajima (6) which considers a weighted average chordal wake distribution in relation to propeller open water charts has been shown

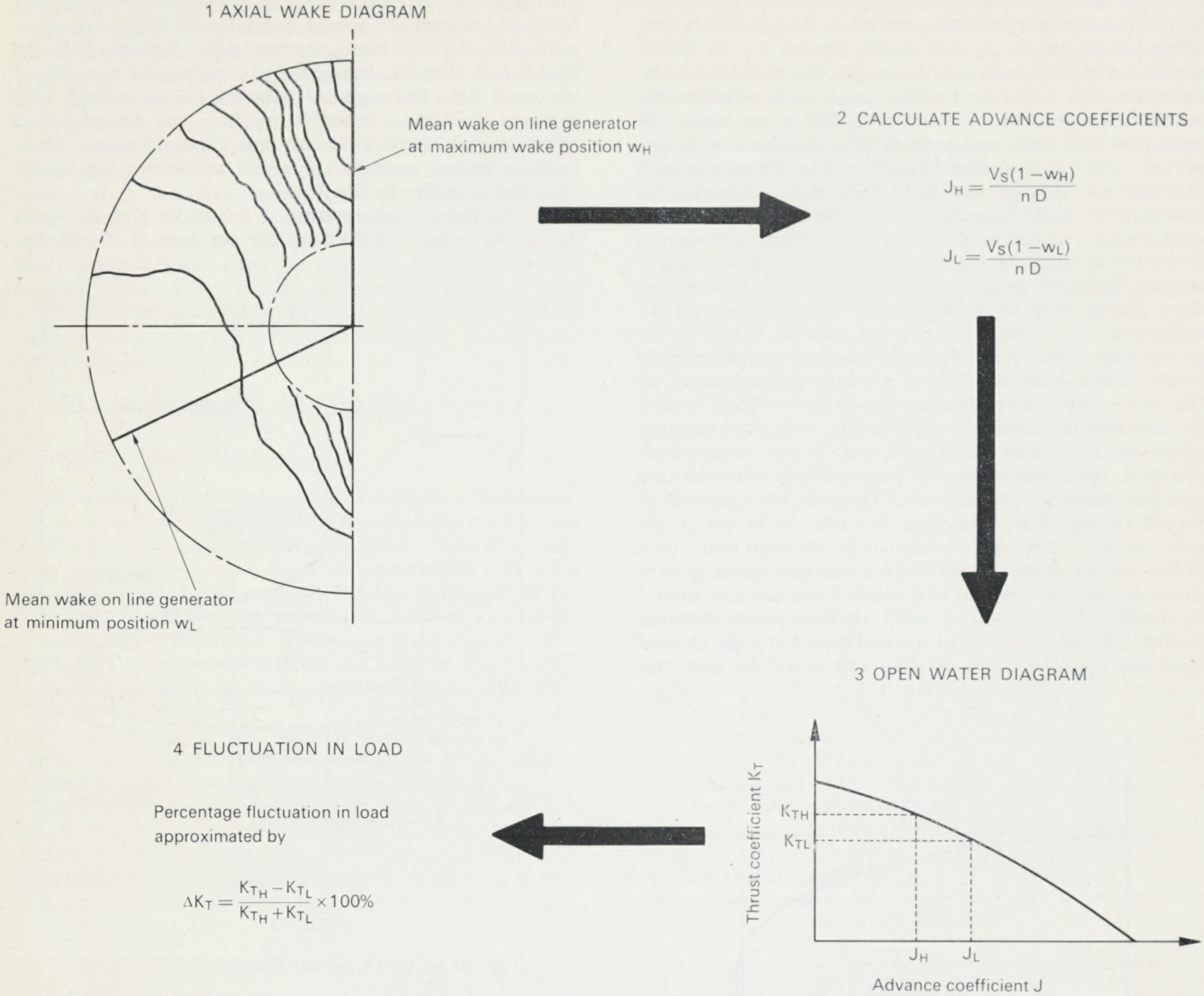


FIG. 5

An Elementary Approach to the Calculations of the Fluctuating Loads.

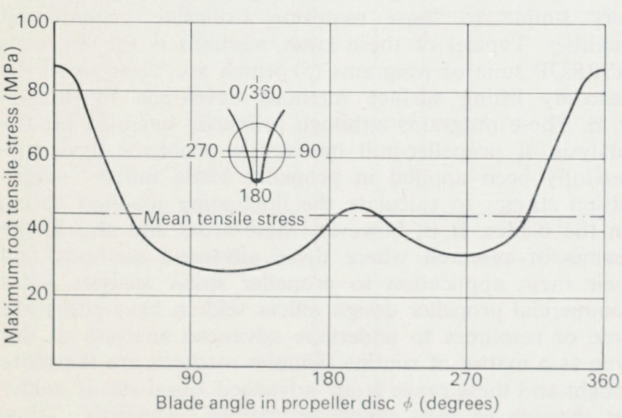


FIG. 6

Cyclic Fluctuations in Blade Root Tensile Stress.

to give good results when compared to unsteady lifting surface theories and is both a valuable and comparatively sophisticated estimation tool for the calculation of fluctuating blade loads. The second approach, which is widely used in practice, is to estimate the fluctuating loads by simply applying a steady state analysis such as indicated in references (3) or (4) to the radial wake distributions at each angular interval in the wake field. Although this approach ignores the effects of sinusoidal gusts on the blade sections it does provide a useful basic calculation procedure. Finally, the simplest approach is that which relates the maximum and minimum mean wakes, assuming the propeller to be represented by a line generator, to the open water propeller characteristics as shown schematically by Fig. 5. Indeed, elementary as this latter method is, it is frequently consistent with the assumptions made concerning both the wake and material properties.

Figure 6 demonstrates the typical fluctuations that can be expected in terms of root tensile stress when related to blade angular position for a single screw vessel, the calculation being performed in this instance by non-steady lifting surface theory as part of a failure investigation by the Society.

2.2 Mechanical Components

The mechanical loadings on a particular section of a propeller blade are a function of the mass of the blade outboard of the section considered and the relative position of its centre of gravity. As such, a system of forces and moments is produced, which can be reduced, for all practical purposes and conventional propeller forms, to a direct centrifugal loading together with a centrifugal bending moment acting about the plane of minimum section inertia. The remaining mechanical loading components have been shown to be negligible for all but highly skewed designs.

In the case of conventional propeller designs the centrifugal loadings can be readily calculated as indicated by Fig. 7, and in general it will be found that they give rise to much smaller stresses than do their hydrodynamic counterparts. The ratio of these mechanical stresses to the hydrodynamic stresses is normally found to be between 0.05 and 0.20.

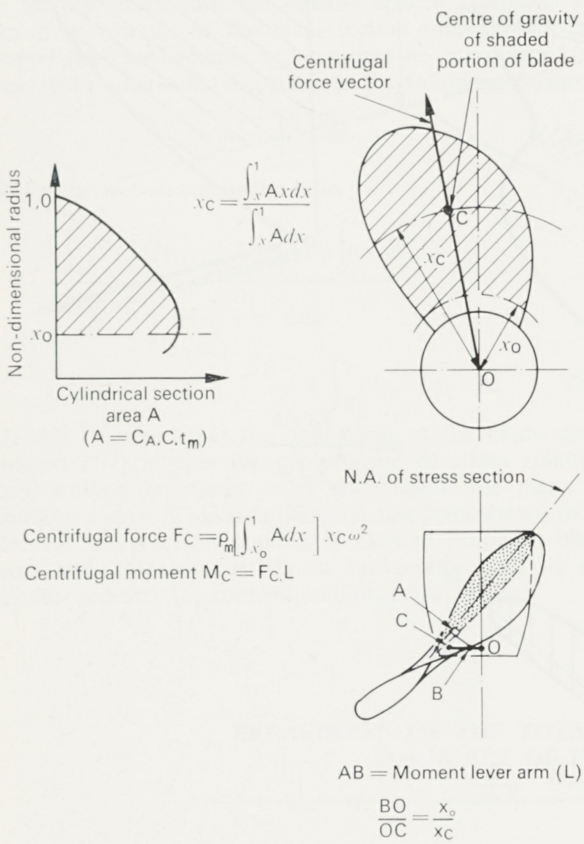


FIG. 7

Derivation of Mechanical Blade Loading Components.

For reference purposes a comparatively detailed treatment showing the derivation of each of the mechanical loading components is given by Schoenherr (7).

2.3 Environmental Loadings

Propeller environmental loadings fall broadly speaking into three major areas of consideration these being the effects of bad weather, of fouling and of ice.

In the case of bad weather, little is known from full scale measurements and reliance is placed on a few model test results and analytical study. The indications are that providing the propeller does not 'break surface', then mean stress levels will increase to some extent during encounters with head seas whereas little appreciable effect is noticed with following seas. If, however, the propeller does not remain submerged then severe fluctuating loads can be imposed on the propeller blades.

The striking of submerged objects and debris is a significant problem for some owners whose vessels operate in foul areas. For such vessels, rather than approach the problem from any fatigue or impact consideration, it is customary to sacrifice hydrodynamic performance to some extent and design the blade sections with thicker leading and trailing edges.

Operation in ice is receiving much attention due to the recent commercial interests in arctic waters. Encounters with ice can be classified in two prime categories, firstly where the ice is in relatively small pieces, and although they may collide with the blade and be ultimately deflected the stress levels are seldom sufficient to cause serious damage to an ice strengthened propeller. The second, and perhaps more important case, is where the ice is presented in larger pieces which can be held against the propeller by either the hull or the ice field. In such cases the propeller is required to cut or "mill" the ice and frequently the forces encountered are such as to create root stresses in excess of the yield for the material. As might be expected, the degree to which a propeller is exposed to ice is to some extent governed by the draught and hull geometry of the vessel. A complete and generally accepted treatment of these conditions has yet to be rigorously formulated, although several authors have published experimental and theoretical studies of which reference (8) is typical.

2.4 Operational Loadings

Since, in general, propeller stressing is carried out for free running conditions at the maximum continuous engine rating, particular consideration must be given to any special operational requirements the vessel may have when determining the stressing basis for propeller blades.

Tugs, trawlers and ice breakers spend significant periods of their life absorbing full power at either zero or reduced speeds. Consequently for these types of vessel high power/low ship speed operating conditions form the basis of the stressing criteria.

Suction dredgers, and indeed some small coasting vessels although using normal stressing criteria, often have the propeller tips thickened slightly to reduce damage should grounding or the touching of sand banks occur.

Finally, in the case of warships which in general spend a considerable amount of time at cruising speeds and only occasionally use full power, it is normal to use a reduced power basis for the strength calculation. Additionally with this class of vessel, as indeed with certain exploration vessels, the blades have to satisfy shock criteria in terms of an appropriate g-factor for underwater explosions.

3 CALCULATION OF BLADE STRESSES

The techniques of propeller stressing have remained in essence unchanged throughout the development of screw propulsion until the beginning of the last decade. Traditionally the cantilever beam method has been the instrument of stress calculation and today forms the cornerstone of commercial propeller stressing practice. This method was originally proposed by Admiral Taylor in the early years of this century and since that time a steady development of the method can be traced. Currently several expositions of this method have been made in the technical literature, all of which, although developing the same basic theme, have differing degrees of superficial emphasis. The version published by Sinclair (9) is typical of the methods in current use today.

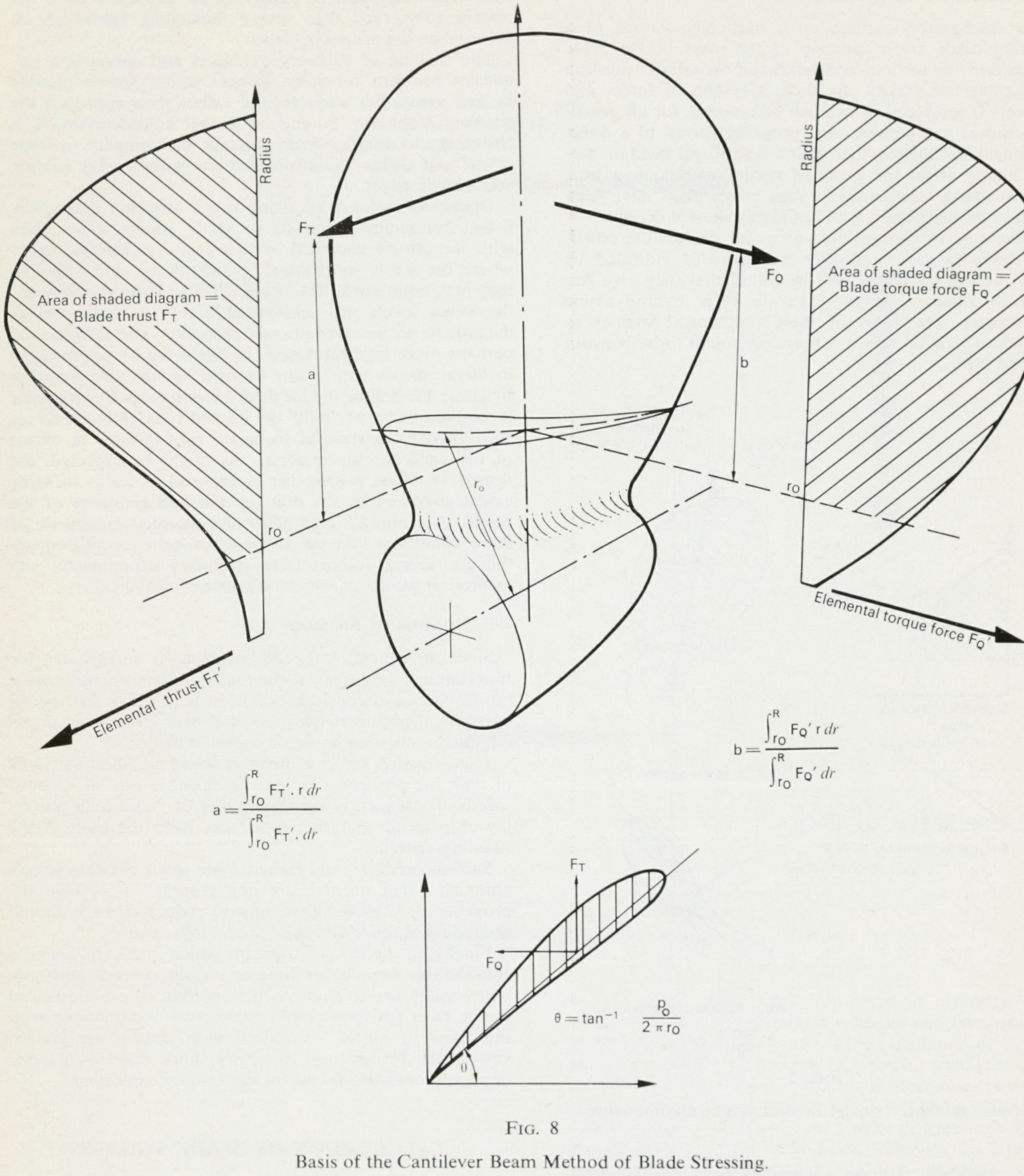


FIG. 8

Basis of the Cantilever Beam Method of Blade Stressing.

The cantilever beam method relies on being able to represent the radial distribution of thrust and torque force loading, as shown by Fig. 3, by equivalent loads at the centre of action of these distributions. Having accepted this transformation, the method proceeds to evaluate the stress at the point of maximum thickness on a blade section by means of estimating each of the components in the equation

$$\sigma = \sigma_T + \sigma_Q + \sigma_{CBM} + \sigma_{CF} + \sigma_\perp \qquad (3.1)$$

Using the definitions of Fig. 8 the bending moment due to hydrodynamic action (M_H) on a helical section of radius (r_o) is given by

$$M_H = F_T.a.\cos\theta + F_Q.b.\sin\theta$$

$$\text{where } \theta = \tan^{-1}\left(\frac{p_o}{2\pi r_o}\right)$$

The total bending moment (M) acting on the blade section due to the combined effects of hydrodynamic and centrifugal action is therefore given by,

$$M = M_H + M_C$$

the centrifugal component (M_C) being the product of the centrifugal force of the blade beyond the stress radius and the distance perpendicular to the neutral axis of the line of this force vector.

Hence the maximum stress on the blade section under consideration is given by

$$\sigma = \frac{M}{Z} + \frac{F_c}{A} \qquad (3.2)$$

where F_C is the centrifugal force exerted by the blade on the section. The calculation of the section area and modulus are readily undertaken from the information contained on the propeller drawing. The procedure being basically to plot the helical section profile according to the information on the propeller drawing, and then divide the section chord into ten equally spaced intervals. The appropriate values of the local section thickness (t) and the pressure face ordinate (y_p) can then be interpolated and integrated numerically according to the following formulae

$$A = \int_o^c t.dc \qquad (3.3)$$

and for the section tensile modulus

$$Z = \frac{2\int_o^c \left[3y_p\,(y_p + t) + t^2\right] t.dc \int_o^c t.dc}{3\int_o^c (2y_p + t)\ t.dc} - \tfrac{1}{2}\int_o^c (2y_p + t)\ t.dc \qquad (3.4)$$

It will be noted that the final form of the blade stress equation (3.2) ignores the components of stress resulting from bending in planes other than about the plane of minimum inertia. This simplification has been shown to be valid for all practical non-highly skewed propeller blade forms and, therefore, is almost universally used by the propeller industry for conventional propeller blades.

Clearly the cantilever beam method provides a simple and readily applicable method of estimating the maximum tensile, or alternatively maximum compressive stress on any given blade section. In order to illustrate the details of this method a worked example appears in the Appendix to this paper. This example considers the evaluation of the mean maximum tensile stress at the 0.25R section of a propeller blade and it can be seen that the calculation is divided into six steps for the sake of convenience. The first two steps are devoted principally to the collection of the necessary data required prior to performing the calculations. Propeller section data is given at a variety of chordal stations, depending upon the manufacturer's preference, consequently, it is usually necessary to obtain values by interpolation at intermediate stations in order to satisfy the requirements of the numerical integration method. It has been found that a conventional Simpson's Rule integration procedure over 11 ordinates is perfectly adequate for calculating section areas and modulii and the appropriate stages for this calculation are outlined by steps 3 and 4. Having evaluated the section properties the calculation proceeds as shown in the remainder of the Appendix.

A method of this type depends for its ease and generality of application upon being able to substitute values for the moment arm lengths a and b without recourse to a detailed analysis of the blade radial loading distribution. Experience has shown that this can be satisfactorily done providing that the propeller type is adequately taken into account. Typically for a conventional fixed pitch propeller the moment arms a and b would be of the order of 0.70R and 0.66R respectively, whereas, for the corresponding controllable pitch propeller these values would be marginally higher. Similar considerations also apply to the position of the blade centroid.

Cantilever beam analysis provides a very useful means of examining the relative importance of the various blade stress components delineated in equation 3.1. Table I shows typical magnitudes of these components expressed as percentages of the total stress for a variety of ship types, and although variations will naturally occur within a given ship group, several important trends can be noted from

TABLE I

BREAKDOWN OF THE TOTAL MAXIMUM ROOT TENSILE STRESS FOR A SET OF FOUR DIFFERENT VESSELS

Component of Stress	SHIP TYPE				
	Bulk Carrier	Fast Cargo Vessel: 5° Astern Rake	Fast Cargo Vessel: 15° Forward Rake	Twin Screw Ferry	High Speed Craft
Thrust	72%	58%	71%	54%	51%
Torque	23%	33%	41%	36%	35%
Centrifugal Bending	1%	5%	−17%	2%	3%
Centrifugal Force	4%	4%	5%	8%	11%
TOTAL	100%	100%	100%	100%	100%

such a comparison. It becomes apparent from the table that the thrust component accounts for the greatest part of the total stress for each class of vessel, and that the direct centrifugal components, although comparatively small for the larger propellers, assume a greater significance for the smaller and higher speed propellers. However, probably most striking is the effect of propeller rake as shown by the two propellers designed for the same fast cargo vessel. These propellers, although designed for the same powering conditions, clearly demonstrate the advantage of employing a reasonable degree of forward rake, since this effect leads to a compressive stress on the blade face. Consequently, this effect can allow the use of slightly thinner blade sections which is advantageous from blade hydrodynamic considerations although, if carried too far, can lead to casting problems. Nevertheless, although the use of forward rake is desirable and indeed relatively commonly used, its magnitude is normally limited by propeller-hull interaction considerations.

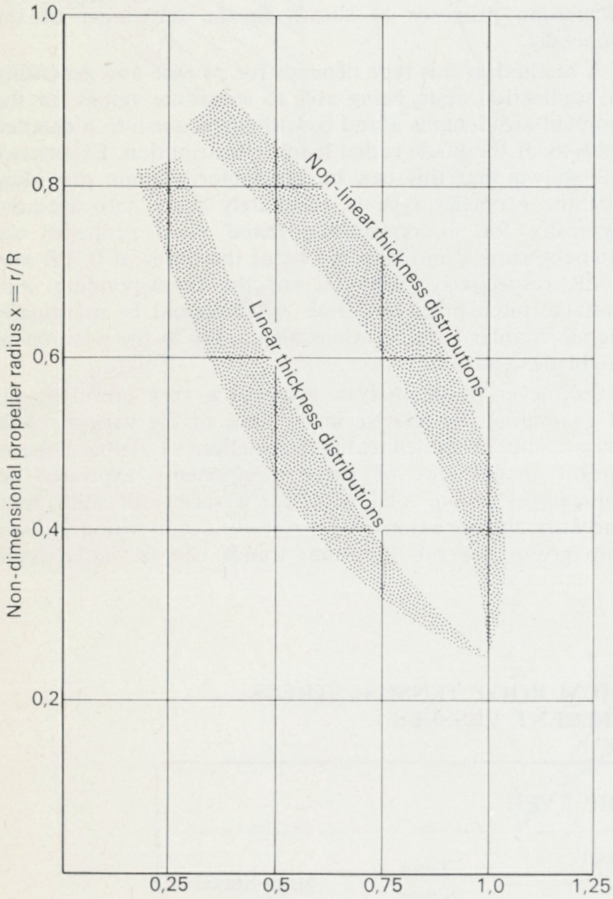


FIG. 9

Comparative Relationship Between Thickness and Radial Stress Distributions.

In addition to providing a procedure for calculating the maximum stress at a given reference section, the cantilever beam method is frequently used to determine radial maximum stress distributions by successively applying the procedure at discreet radii over the blade length. If such a procedure is adopted then the resulting blade stress distributions have the form shown by Fig. 9, where the typical bands of radial stress distribution for both linear and non-linear thickness distributions can be seen. The non-linear distribution is the most commonly employed, since although it allows higher blade stresses, it permits a lower blade weight and also the use of thinner blade sections which is extremely advantageous from both the hydrodynamic efficiency and cavitation inception viewpoints. Linear thickness distributions are frequently adopted in the case of many smaller propellers for the sake of simplicity in manufacture. This tenet is, however, sometimes mistakenly employed, since many small high speed patrol craft have presented considerably more difficult design problems than the largest bulk carrier. Additionally this latter type of distribution is frequently employed in towing and trawling situations in order to give an added margin against failure.

Although the cantilever beam method provides the basis for commercial propeller stressing, it does have certain disadvantages. These become apparent when the calculation of the chordal stress distribution is attempted, since it has been found that the method tends to give erroneous results away from the maximum thickness location. This is partly due to assumptions made about the profile of the neutral axis in the helical sections since the method as practically applied assumes a neutral axis approximately parallel to the nose-tail line of the section. However, the behaviour of propeller blades tends to indicate that a curved line

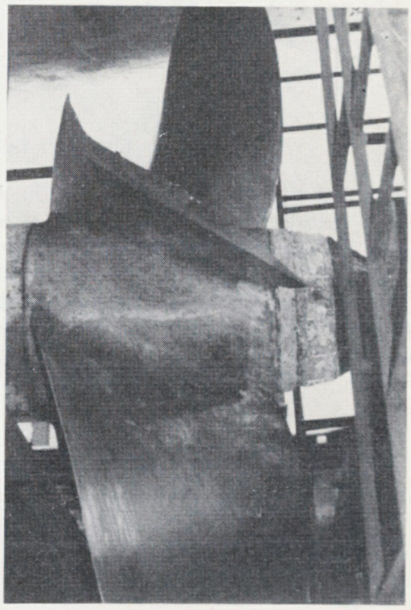


FIG. 10

Propeller Blade Failure.

through the blade section would be more representative of the neutral-axis when used in conjunction with this theory. Complementary reservations are also expressed since the analysis method is based on helical sections, whereas observations of blade failures tend to show that propellers break along "straight" sections as typified by the failure shown in Fig 10.

In order to overcome these problems intensive research efforts led in the first instance to the development of methods based upon shell theory. However, as computers became capable of handling more extensive computations, work concentrated on the finite element approach using plate elements initially and then more recently isoparametric and superparametric solid elements. Typical of these

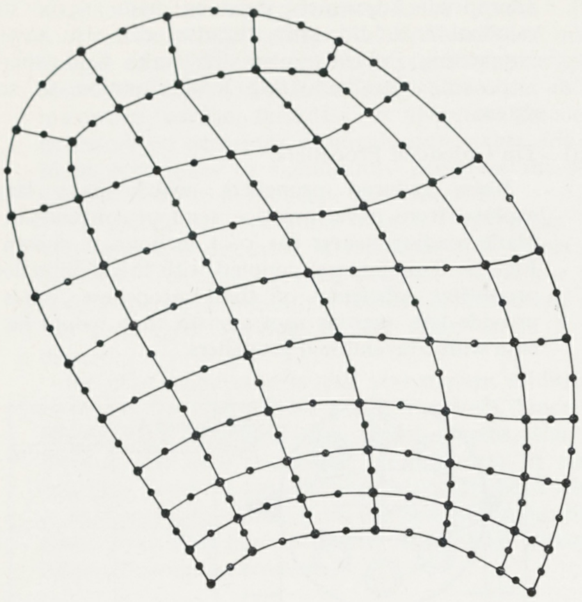


Fig. 11

Developed Finite Element Mesh for a Propeller Blade.

latter methods is the approach developed by Atkinson (10) which has subsequently been adapted for use by the Society. The principal advantage of these methods is that they can evaluate the stresses and strains over a much greater region of the blade than can the simpler methods, assuming of course, that it is possible to define the hydrodynamic blade loadings accurately.

In order to evaluate blade stress distributions by finite element methods of the type referenced, the propeller blade geometry is discretized as shown in Fig. 11. Then by defining the surface pressure distributions in both chordal and radial directions, a detailed stress analysis can be conducted, the results of which may be presented in the form shown by Fig. 12. Results such as these are important as they clearly show both the magnitude and directions of the principal stresses for the propeller under analysis. Distribution of this type are typical for most non-highly skewed propeller forms, the principal features of which being a relatively constant tensile distribution of stress over the majority of the pressure face, together with a variable distribution ranging from a moderate tensile stress at the leading and trailing edges to a maximum compressive stress around mid chord over the suction face. With these distributions the maximum compressive stress is normally found to be greater than its tensile counterpart. Furthermore, the minimum principal stress, which lies in an approximately chordal direction, tends to be small when compared to the radial component. In the region of the propeller boss, just above the root fillets, the highest stresses appear to lie within the middle two thirds of the chord length with comparatively low stresses outside this region in the vicintiy of the leading and trailing edges.

Despite the power of these advanced methods in being able to evaluate the blade stress distribution, problems are experienced in calculating the stresses in the tip regions of the blade resulting from the finite element mesh definitions, and also the accuracy of the hydrodynamic loading data. Fortunately however, these regions of the blade, notwithstanding any impact or fouling considerations, tend to be of secondary importance for the greater majority of vessels.

At present, two principal methods are available for the stress analysis of propeller blades under load. The cantilever beam method, since it provides both an economic and well proven solution, is almost universally used for commercial design purposes although it does have limitations in certain

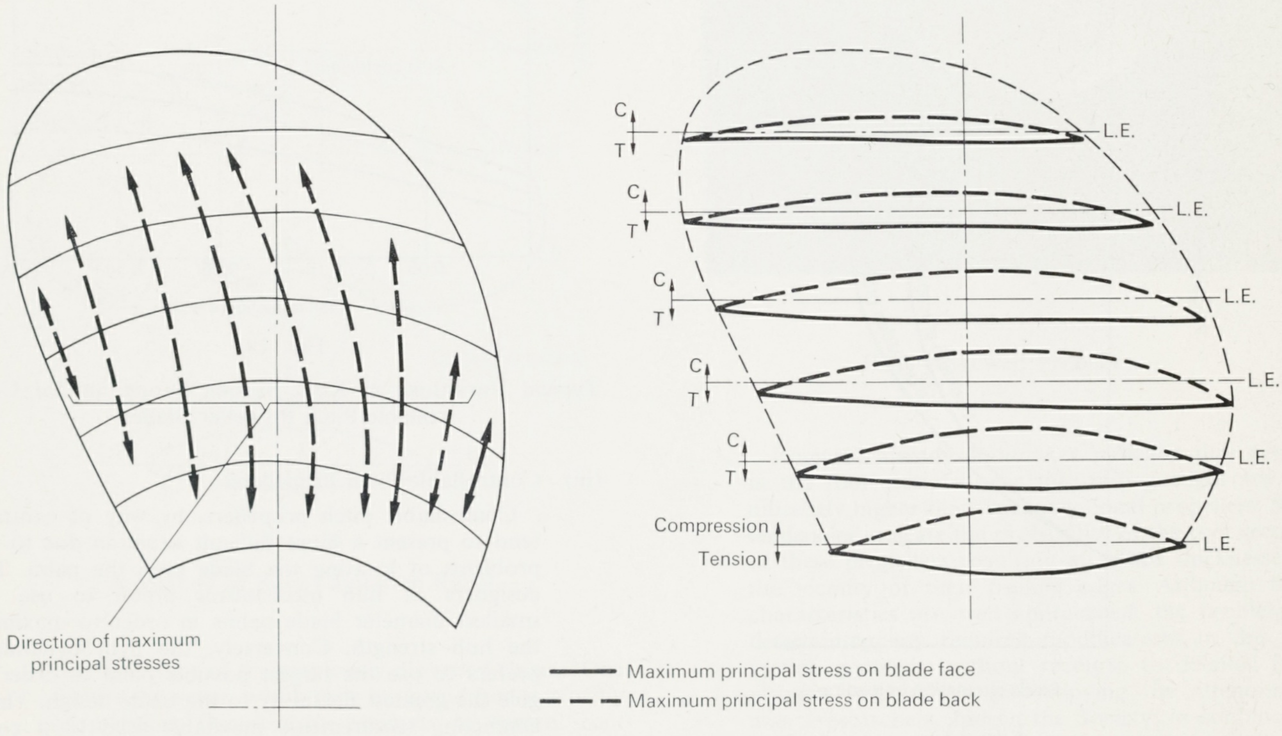


Fig. 12

Distribution of Maximum Principal Stresses on a Propeller Blade.

applications. Alternatively, the finite element approach overcomes many of the deficiencies of the cantilever beam method but requires extensive input, detailing the radial and chordal loading characteristics, in addition to the other requirements of extensive computation facilities.

The detailed design of propeller thickness distributions tends to be a matter of individual choice between the propeller manufacturers, based largely on a compromise between strength, hydrodynamic and manufacturing considerations. Additionally, in the case of the majority of vessels, there is also a requirement for the propeller blade thickness to meet the requirements of one of the Classification Societies. In the case of Lloyd's Register of Shipping, as indeed with most of the other Classification Societies, these rules are based upon the cantilever beam method of analysis. The present Rule formula used by the Society is basically derived from equation 3.1. In this formula the assumption is made that the sum of the direct centrifugal stresses and the stresses in planes other than the plane of minimum section inertia is small. Additionally, in order to relate the thrust and torsional stress components, thereby simplifying the resulting formula further, an empirical relationship expressing the ratio of the thrust to torque coefficients for free running propellers is included.

The techniques of propeller blade stressing discussed in this section are applied to all types of propeller and it is therefore, of interest to review the special characteristics of particular types of propeller in relation to the conventional propeller.

(i) Ducted propellers:

As ducted propellers, in common with transverse propulsion unit propellers, tend to have rather more heavily loaded outer sections than conventional propellers the effective centres of action of the hydrodynamic loading tend to act at slightly larger radii.

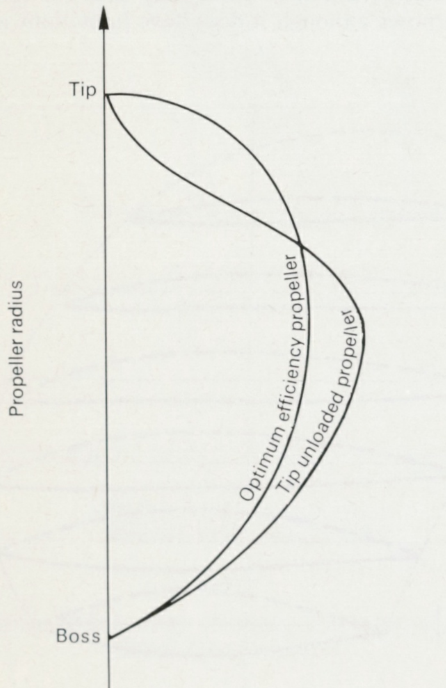


Fig. 13

Comparison Between Tip Unloaded and Optimum Efficiency Radial Loadings.

However, it must also be remembered that since a proportion of the total thrust is taken by the duct the appropriate adjustment must be made in the stress calculation. Additionally, the duct can also have an attenuating influence over the wake field, thereby improving the fluctuating load situation to some extent.

(ii) Tip Unloaded Propellers:

Noise reduced propellers, which have largely evolved from naval practice, tend to concentrate the blade loading nearer the root sections as shown by Fig. 13. This feature, coupled with the slightly lower propulsive efficiency of these propellers, tends to provide less onerous root stresses than would be the case with conventional propellers.

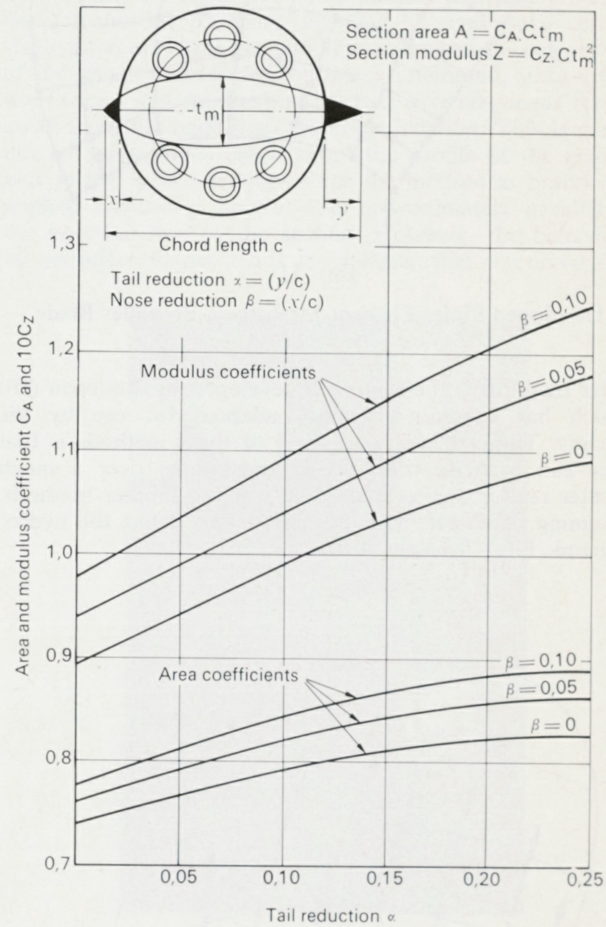


Fig. 14

Typical Variations in Root Section Properties for Controllable Pitch Propeller Blades.

(iii) Controllable Pitch Propellers:

Controllable pitch propellers, by way of contrast, tend to present a more difficult situation due to the problems of locating the blade onto the palm. The designers of hub mechanisms prefer to use the smallest diameter blade palms in order to maximise the hub strength. Conversely, the hydrodynamicist prefers to use the largest possible palm in order to give the greatest flexibility to the blade design. These conflicting requirements inevitably lead to a compromise which frequently results in the root sections of the blade being allowed to "overhang" the palm. This feature, although introducing certain discon-

tinuities into the design, is not altogether undesirable since it allows both the root section modulus and area to be increased as shown for a typical C.P.P. root section profile by Fig. 14. Additionally, in many designs of a C.P. propeller the blade bolting arrangements are such as to place a further limitation on the maximum section thickness. It therefore becomes necessary on occasions, although undesirable, for the blade bolt holes to significantly penetrate the root fillets in order to fit the blade onto the palm.

The modes of operation of a C.P. propeller are very varied as discussed in reference (11). Generally however, from the stressing point of view these off-design operating conditions remain unconsidered unless prolonged working in any given mode is indicated.

Ice class requirements can also present additional problems for controllable pitch propellers. Since the blades have restricted root chord lengths, the additional ice class thickness requirements in some instances result in root section thickness/chord ratios in excess of 0.35, which from the hydrodynamic viewpoint gives both poor efficiency and greater susceptibility to cavitation erosion.

(iv) High Speed Propellers:

High speed propellers generally have better inflow conditions than their larger and slower running counterparts, although poorly designed shafting support brackets are sometimes troublesome. Consequently, high wake induced cyclic loads are not usually a problem unless the shafting is highly inclined. Centrifugal stresses, as shown by Table I, tend to take on a greater significance due to the higher rotational speeds and, therefore, greater attention needs to be paid to the calculation of the mechanical loading components.

Naturally these propellers, if in either a ducted or controllable pitch form, can take on some of the

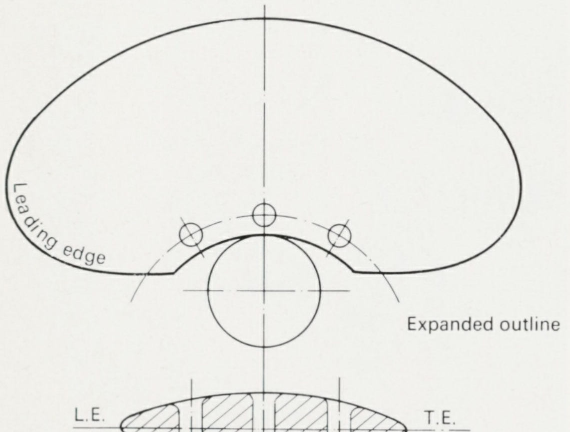


FIG. 15

A Method of Root Cavitation Relief.

characteristics of the previously discussed classes. One feature, however, which may be introduced is worthy of mention. Occasionally attempts to control root cavitation erosion have resulted in a system of holes being bored normal to the blade surface along the root section as sketched in Fig. 15. Whilst the purpose of these holes is to relieve the pressure differential across the blade section, their presence necessitates a careful review of the root section thicknesses. Additionally large blending radii need to be specified so as to merge the holes into the blade surface in as fair a way as possible.

(v) Highly Skewed Propellers:

The comparatively recent emergence of the highly skewed propeller into merchant practice has introduced a further complication into blade stress analysis procedures. Although finite element methods can adequately analyse these propellers the traditional cantilever beam method is not so well placed, especially where the skew becomes excessive as shown in Fig. 16.

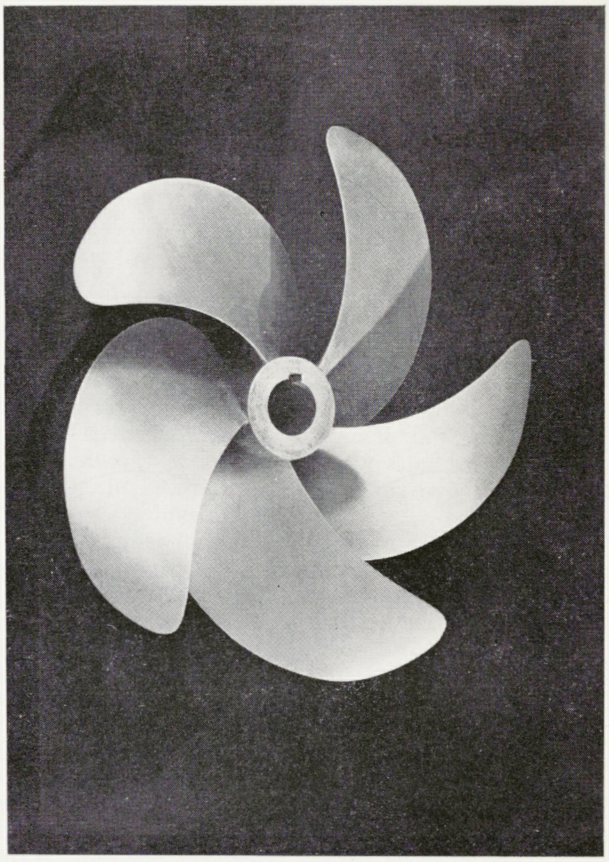


FIG. 16

Highly Skewed Propeller.

Research already undertaken indicates that stresses in the root sections near the trailing edges are significantly higher than in conventional propellers. Such tendencies indicate the probability of the root sections of these propellers requiring increased thicknesses in the vicinity of their trailing edges. Although these characteristics are well appreciated, the problem of determining any required modifications to the root section geometry without recourse to detailed finite element calculations is occupying the attention of many researchers. Indeed the Society, in conjunction with industry, is actively pursuing a programme of research in this field from both theoretical and experimental viewpoints.

Traditionally the principal material of propeller manufacture has been high tensile brass. However, with the advent of increasing propulsion powers, which introduced problems of erosion and corrosion on a much wider scale than had been previously known, other materials such as the manganese-aluminium and nickel-aluminium bronzes made their appearance. These other materials have now been in common use for some thirty years and it is interesting to note their relative use as shown by Fig. 17 for all types of propeller over 2000 B.H.P. This figure, which shows the relative proportions of the material usage for propellers classed with the Society since 1960, clearly demonstrates the increasing preference for nickel-aluminium bronze at the expense of the other copper alloys.

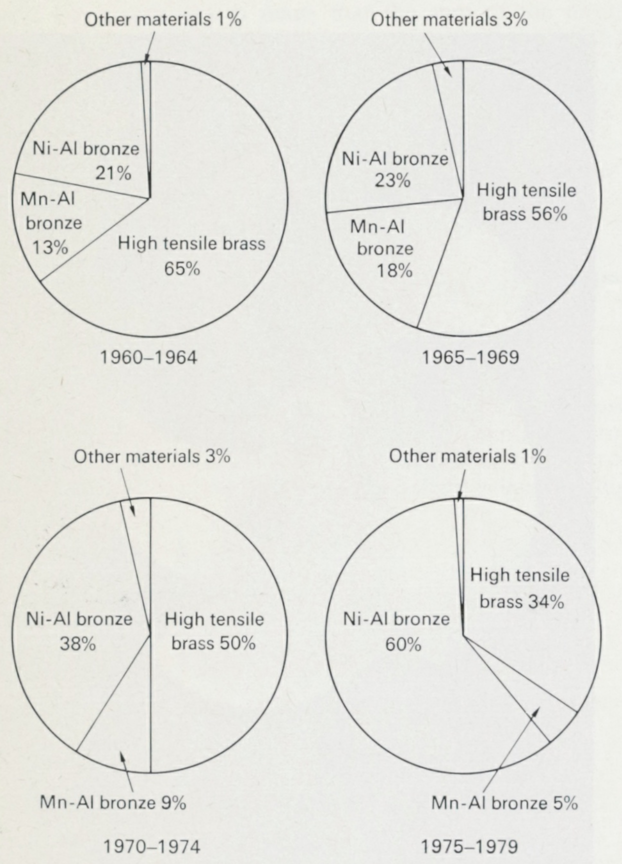


FIG. 17

Comparative Usage of Propeller Materials.

The other materials of manufacture, namely stainless steel, carbon steel, cast iron and the polymers account for only an average 2% of the ships classed with the Society during the period under review. In particular, cast iron which at one time was a common material especially for spare propellers is now rarely used and the polymers, although one or two research studies have been undertaken for larger vessels, are confined to the power boat end of the market.

For comparison purposes the typical mechanical properties of these materials as determined by separately cast test pieces are shown in Table II.

From elementary calculations it can be shown that for a propeller working behind a vessel, 10^9 cycles of alternating stress can be attained in a matter of 20 years for a large bulk carrier and correspondingly sooner for many smaller vessels. Consequently, the corrosion fatigue properties of the materials become of paramount importance in the design of marine propellers. However, if fatigue tests on these materials were carried out to this number of cycles and over a sufficiently large number of specimens for the results to become meaningful, the necessary design data would take an inordinately long time to collect. Consequently, it is more usual to conduct tests up to 10^8 reversals and although it can be argued that this data tends to be suspect when extrapolated to 10^9 cycles, the criteria of assessment are normally based on the lower figure for marine propellers.

Throughout the development of propeller materials many tests using the Wöhler fatigue testing procedure have been made for the various materials. However, these tests have several limitations in this context, since they do not readily permit the superimposition of mean loads on the specimen and the stress gradients across the test specimen tend to be large. For these reasons and furthermore, since the exposed areas of the test piece tend to be small, the results from these tests are used primarily for qualitative analysis purposes. In order to overcome these difficulties and thereby provide quantitative fatigue data for use in propeller design, fatigue testing machines such as the one shown by Fig. 18, which is located at the Society's Research Laboratory, have been designed. Machines of this type are usually able to test material specimens of the order of 75mm in diameter and in addition to applying a fluctuating component of stress, a mean stress can also be superimposed by using hollow specimens, thereby, permitting pre-stressing by means of a suitable linkage. In order to simulate the corrosive environment a 3% sodium chloride solution is sprayed onto the specimen in the

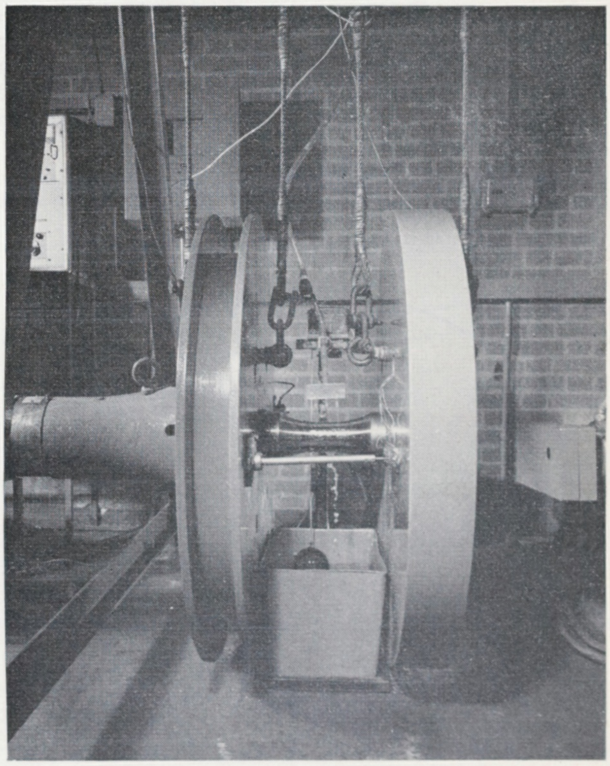


FIG. 18

Typical Fatigue Testing Machine used for Propeller Material Investigation.

TABLE II

TYPICAL COMPARATIVE MATERIAL PROPERTIES

Material		Modulus of Elasticity (kgf/mm^2)	0.15% Proof Stress	Tensile Strength (kgf/mm^2)	Brinell Hardness Number	Specific Gravity
Copper Based Alloys	High Tensile Brass	1.05×10^6	19	45–60	120–165	8.25
	High Manganese alloys	1.20×10^6	30	66–72	160–210	7.45
	Nickel-aluminium alloys	1.25×10^6	27.5	66–71	160–190	7.6
Stainless Steels	13% Chromium	2.0×10^6	45.5	69.5	220	7.7
	Austenitic	1.9×10^6	17	50.5	130	7.9
	Ferritic-Austenitic	1.8×10^6	55	80	260	7.9
Cast Iron	Grey cast iron	1.1×10^6	—	23.5	200	7.2
	Austenitic S.G.	1.1×10^6	—	44	150	7.3
Polymers	Nylon	0.008×10^6	1.1	4.7	—	—
	Fibreglass	0.14×10^6	—	20	—	—

majority of cases. The use of this solution to simulate sea water is generally considered preferable for testing purposes since the properties of sea water are found to vary considerably with time and unless the sea water is continuously replaced, it decays to such an extent that it becomes, unrepresentative.

Testing machines of the type shown in Fig. 18 have been used extensively in order to examine the behaviour of various propeller materials. Fig. 19, by way of demonstration of these researches, shows the comparative behaviour of three copper alloys based on a fatigue life of 10^8 cycles as determined by the authors of reference (12). From these test results the superior corrosion fatigue

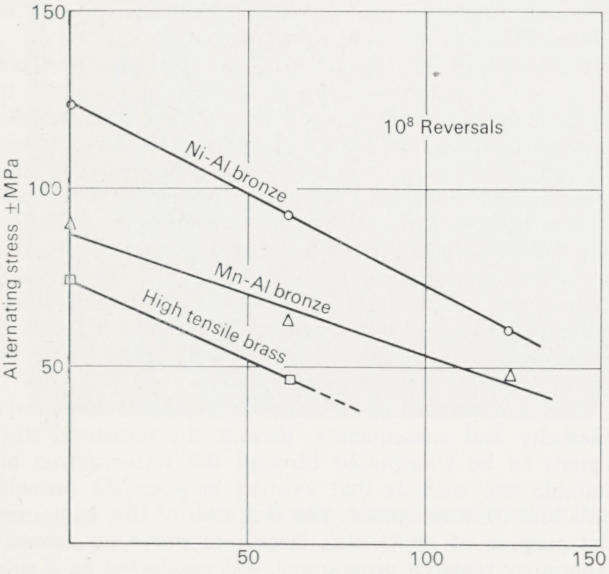


Fig. 19

Effect of Mean Stress and Material Type on Fatigue Life.

properties of the nickel-aluminium bronzes become evident. In establishing these results extreme care is necessary in controlling the solidification and cooling rates of the test specimens after pouring in order that they can correctly simulate castings of a significantly greater weight. In the case of Fig. 19 a simulation of a casting weight of around 4 tonnes was attempted.

Casting size has long been known to affect the material properties as witnessed by the sometimes significant differences between test bar results and the mechanical properties of the blade when destructively tested. For these reasons controllable pitch propeller blades are generally believed to have superior mechanical properties to monoblock propellers of an equivalent size. Many attempts have been made to correlate this effect by using a variety of parameters. The approach by Meyne (13), in which tensile strength and proof stress are plotted to a base of propeller weight divided by the product of blade number and blade area, gives encouraging results. This approach which is effectively defining a pseudo blade thickness correlation parameter appears to be rather more effective than simpler methods using blade weight alone. The correlation of elongation with casting size is, however, still far from resolved.

Casting quality has a profound influence on the life of a propeller in service. The defects found in copper alloy propellers are generally attributable to porosity in the form of small holes resulting from either the releasing of excess gases or shrinkage due to solidification. Alternatively, the defects can be oxide inclusions in the form of films of alumina, formed during the pouring stage of propeller manufacture, which have a tendency to collect near the skin of the casting. The location of a defect is obviously critical, since defects in the centre of the blade section and on the suction face are less concerning than those located on or near the pressure face in the mid-chord region just above the run-out of the fillet radii. Considerations of this type lead onto the concept of acceptable defect criteria for marine propellers which in turn introduces the subject of fracture mechanics.

The visual characteristics, as shown by Fig. 20, of a propeller blade which has failed by fatigue action are generally similar for all propellers, athough in some cases the beach marks are more clearly visible than in others. Attempts at correlating the relative geometric form of these markings during crack growth have been made from observations on failed propellers. However, although encouraging results have been obtained to date, further work is required

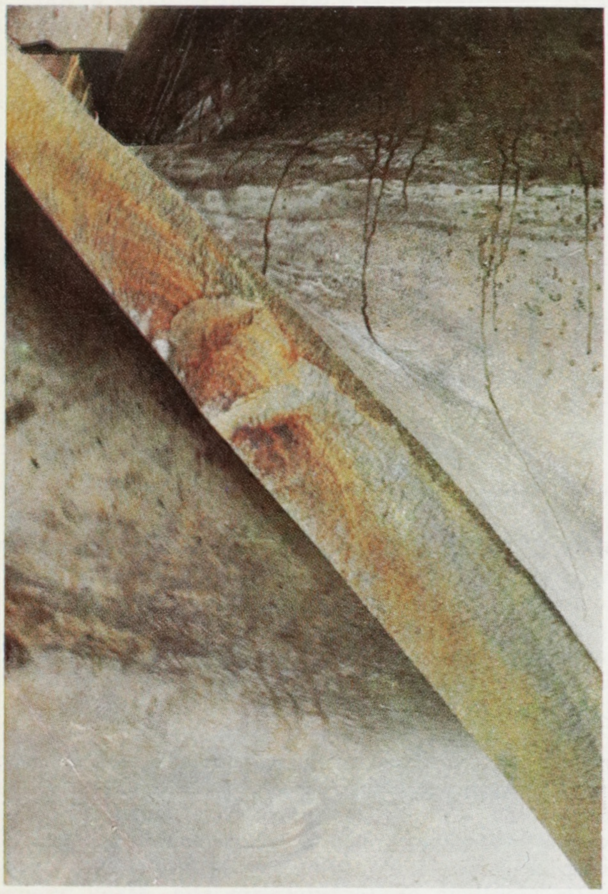


FIG. 20

Fatigue Failure of Propeller Blade.

before any relationship can be generally established. The advantages of obtaining such a relationship are that the aspect ratio of the crack can be directly related to the stress intensity factor, which may then be used in conjunction with fracture toughness information to assess acceptable defects and crack propagation rates. Work by Røren (14) and Tokuda (15) have given coefficients for the stage two crack propagation equation,

$$\frac{da_c}{dN} = c(\Delta k)^m$$

as delineated in Table III, these results being derived from samples cut from failed propeller blades. The tests for the Mn-Al alloy used the centre slotted type specimen, whilst those for the Ni-Al alloy were defined as being of the Wedge Opening Load type.

Residual stresses are present in all castings. However, the levels of these stresses are usually only high enough to impair service life after the propeller has been subjected to relatively severe mechanical or thermal action. The levels of residual stress in a new propeller are naturally dependent on the manufacturing process both during the casting and finishing operations. As such it is considered that the temperature gradients during the cooling in the mould have an important influence in this respect. The result of these stresses, in those cases where they are of a sufficiently high magnitude, is stress corrosion cracking and it was found that high tensile brass is the most susceptible of all the propeller materials in this respect. The subject of residual stresses is perhaps the least well documented owing mainly to difficulty of measurement which of necessity involves destructive tests. However, in the relatively few cases where measurements have been taken stresses as high as 17-18 kgf/mm^2 have been noted, although it has been more common to find somewhat lower figures of either a tensile or compressive nature. Residual stresses can of course be relieved by heat treatment, but in the case of a propeller this tends to be an expensive operation and consequently, is not generally adopted for new propellers.

Incorrect repair procedures for blade straightening or welding have been found to induce residual stresses in high tensile brass and high manganese alloys sufficient to cause stress corrosion cracking. Indeed such characteristics have also been observed where the boss has been heated too intensely during propeller removal operations. Little is known about the corrosion fatigue strengths of welded castings, however research on this subject has been initiated in the last few years. Nevertheless, it is known that good quality welds performed on the aluminium bronzes and devoid of post heat treatment lose between one and two thirds of their strength. Service experience, therefore, dictates that in the regions where high fatigue loading in the presence of mean tensile stresses is likely to be experienced, such as the pressure face of the blade near the root, then welding should be prohibited. This philosophy is clearly reflected by the propeller repair procedures indicated by the Society's Rules.

5 FULL SCALE MEASUREMENT

By comparison with the amount of theoretical work undertaken on the subject of propeller strength, the number of full scale measurement exercises have been few. The reason for this comparative dearth of full scale data has undoubtedly been due to the difficulties hitherto encountered in instrumenting the chosen ship.

Until recently, if propeller stress measurements were contemplated, it has always been necessary to conduct the wires from the strain gauges, located on the propeller, through a hollow tail shaft to a system of slip rings inside the ship. Despite the obvious disadvantages of this method, some notable full scale studies have been conducted and it is these trials which at the present time form the nucleus of our full scale data. Clearly, therefore, a new method of propeller strain measurement was required which would by-pass the hollow shaft difficulties. To fulfil this need a technique pioneered by the Society in co-operation with the government and industry was given its first trial in the North Sea some two years ago.

This new method of measurement is based upon radio-telemetry and consequently, permits the measured strain signals to be transmitted through the water across any suitable gap such as that existing between the propeller boss and the rope guard. The first trial of this equipment, the purpose of which was largely to prove an extensive laboratory research programme, was conducted on a small coasting vessel and attempted the simultaneous recording of twelve information channels from the propeller. Fig. 21 shows the distribution of strain gauges on both the suction and pressure faces of the propellers that were used for

TABLE III

MATERIAL CONSTANTS FOR CRACK PROPAGATION EQUATION

Material	c	m	Mean Stress (kgf/mm²)	Condition
Mn Al Bronze	6.6×10^{-11}	3.7	7.0	Sea water at 4 Hz
Ni Al Bronze	4.97×10^{-13}	4.7	0	Simulated sea water at 2.5 Hz
	3.37×10^{-14}	5.2	0	Simulated sea water at 5 Hz (Threshold value = 25 kgf/mm$^{3/2}$)

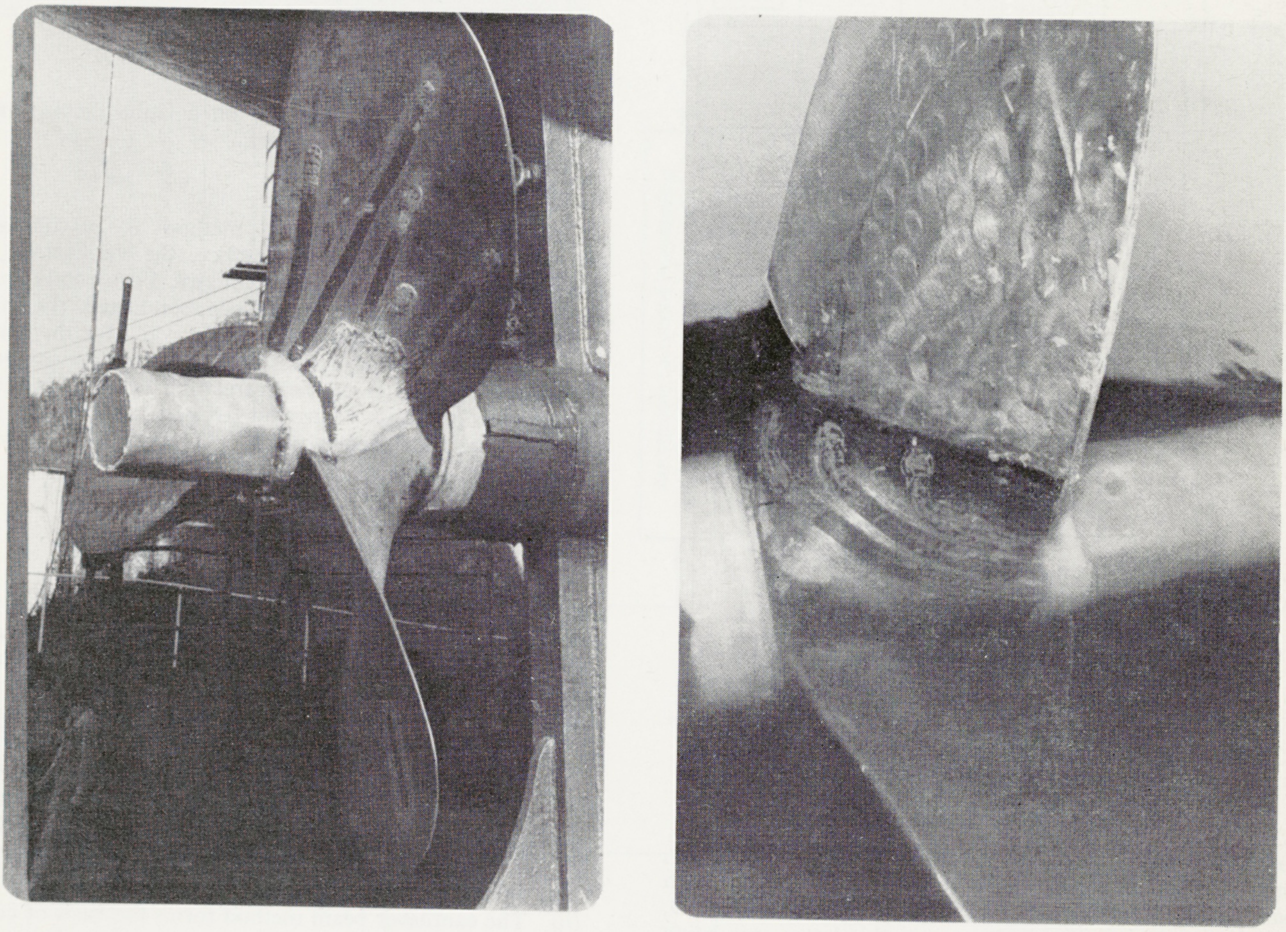


Fig. 21

Strain Gauge Arrangement used on the Sea Trials of the TID/AES Measurement System.

these trials. Additionally, from this figure, it can be seen that the transmitting equipment had to be located aft of the propeller nut owing to the limited clearances which exist at the forward end of the propeller on these small vessels. The trials, which were conducted over a period of some weeks, adequately proved both the instrumentation and gauge bonding technique in addition to providing valuable full scale data such as that typified by Fig. 22 which relates

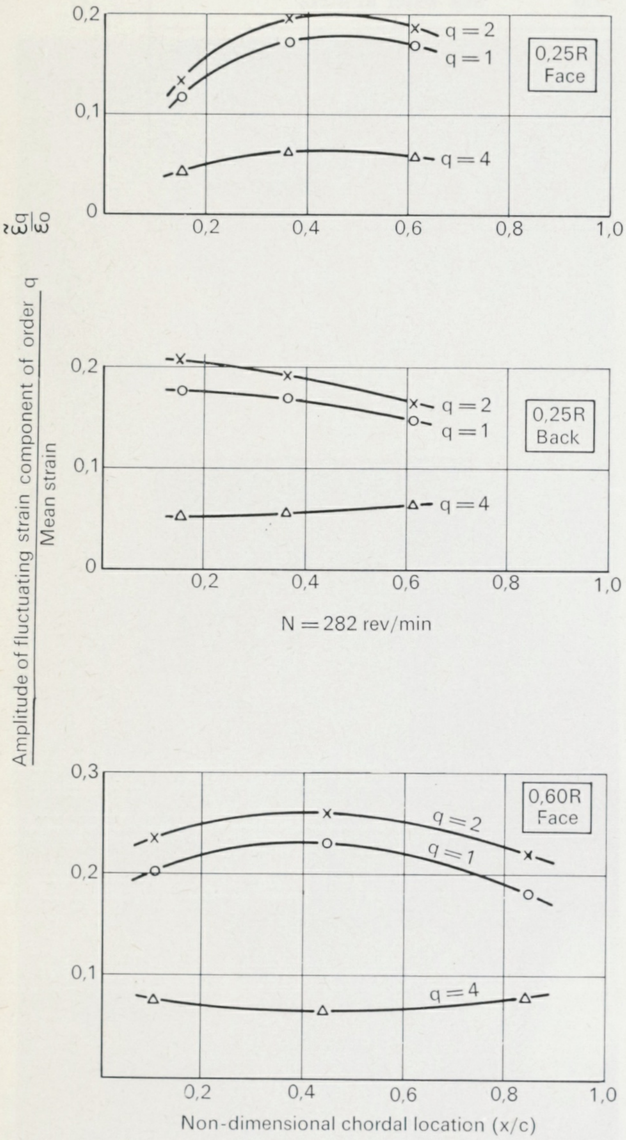


FIG. 22

Measured Chordal Strain Fluctuations.

to the chordally fluctuating blade strains. Subsequently, this method has been applied to a fully reversing, high performance controllable pitch propeller as seen in Fig. 23, the signal transmission equipment in this latter case being mounted on the forward face of the propeller hub under the rope guard.

The results of full scale measurements have in general correlated well, both in terms of distribution and magnitude, with calculated results. Measurements taken by Wereldsma (16) in a detailed study of the root section of a propeller fitted to a 42,000 ton tanker, clearly substantiate the findings of finite element studies by showing that the leading and trailing edges of the blade at the root are relatively unstressed with respect to the more centrally located regions. Furthermore, from this work and also further substantiated by the coasting vessel trials conducted by the Society, it is seen that the maximum principal stresses tend to lie in an approximately radial direction whilst the minimum principal stresses, which are predominantly in a chordal direction, can be seen as largely insignificant.

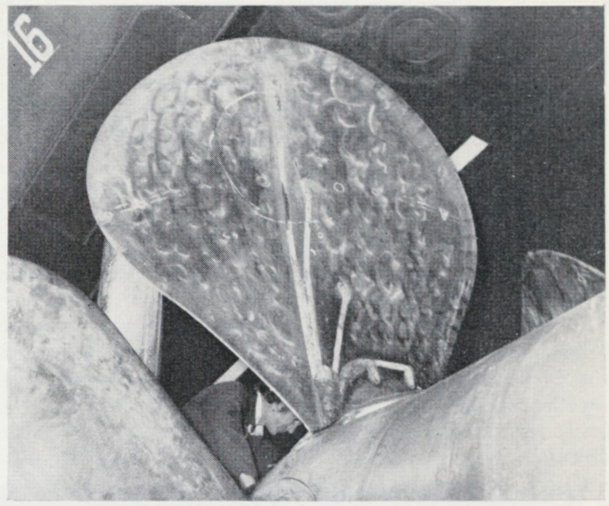


FIG. 23

Strain Gauge Arrangement used on a Controllable Pitch Propeller.

Since the cantilever beam method is prominently featured in propeller design practice, the verification of this approach is of considerable interest. Fortunately from such full scale studies as have been conducted, the indications are that the method is generally valid for the determination of the maximum tensile stress for conventional propellers. In these cases the correlation tends to indicate a maximum deviation of around ten per cent between the calculated and measured values.

6 CONCLUDING REMARKS

The preceding discussion has been largely a review of the science, or as many practitioners would justifiably argue 'the art', of propeller stressing at the present time. From a discussion of this type, several ideas emerge which are fundamental to the subject of propeller strength and these are briefly recalled in the following paragraphs.

(i) The principal blade loading components derive from both the steady and fluctuating parts of the wake field and, therefore, the derivation of these loading components can be no better than the accuracy of the wake field data.

(ii) The cantilever beam method forms the basis of commercial propeller stressing practice whilst finite element methods tend to be confined to research or specialised investigation.

(iii) The basis for blade strength calculations is normally the maximum continuous engine rating in association with the free running ship condition unless special operating conditions exist, such as for example, towing, ice breaking or underwater explosions.

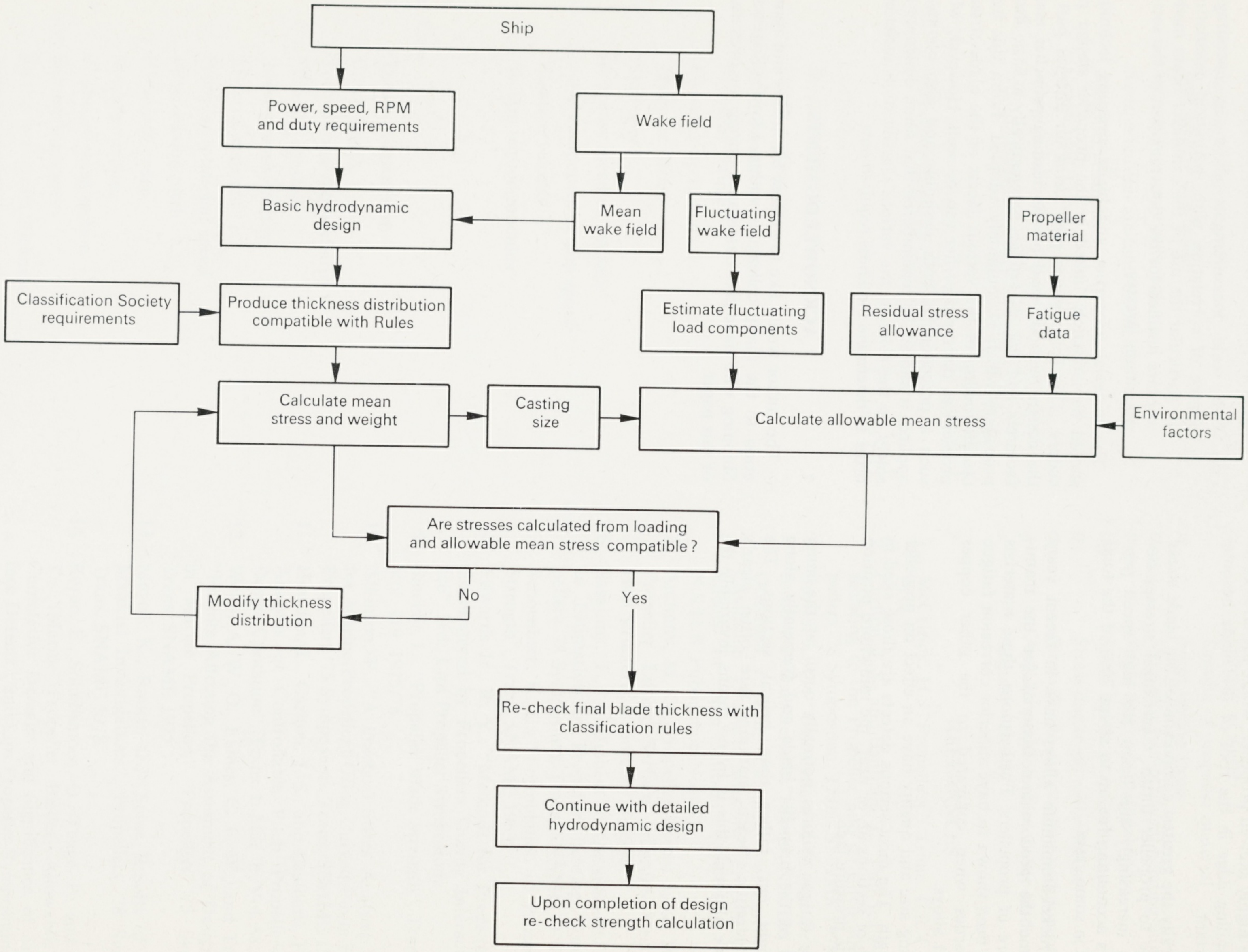


FIG. 24

Integrated Propeller Blade Design Procedure.

(iv) The choice of radial thickness distribution tends to to be a matter of compromise between strength, hydrodynamic and manufacturing considerations.

(v) Propellers normally have similar blade stress distributions in their design conditions except for the case of the highly skewed propeller, where the stresses at the trailing edge in the root of the blade become important.

(vi) Generally the greatest component of the blade stress is due to propeller thrust. Centrifugal stresses become increasingly significant for high speed propellers accounting for up to about 20% of the total stress in some cases.

(vii) The nickel-aluminium alloys have in recent years become the predominant material for the manufacture of propellers. Furthermore, these materials have been shown to have superior corrosion fatigue properties when compared to the other copper based alloys.

(viii) Casting size and quality have an effect on propeller strength. The most serious defects are those sited in the root sections at, or near, the mid-chord position on the pressure face.

(ix) Blade fatigue failures normally occur at the inner radii of the propeller blade and frequently along 'straight cut' rather than helical sections. The characteristic 'beach markings' are often clearly visible although this is by no means invariably the case.

(x) The adherence to manufacturer's repair procedures is essential if stress corrosion cracking and similar problems are to be avoided in subsequent service.

(xi) The Society's recently developed radio-telemetry method significantly reduces the problems of full scale propeller strain measurement.

(xii) Full scale measurements show an encouraging degree of correlation with theoretical calculations. In particular the use of the cantilever beam method appears justified for the determination of the section maximum stresses.

The material properties and blade stressing techniques should be intimately linked in the propeller design procedure. This basic philosophy forms an integral part of the design methods used by the leading propeller manufacturers and Fig. 24 typifies schematically a basic design procedure which is commonly adopted. From this figure the interaction of the various facets of the blade strength problem as discussed earlier can be seen. However, whilst such a procedure is both desirable and also commonly applied, it should be remembered that some designers rely solely on the rules of the various classification societies in order to determine thickness requirements.

7 ACKNOWLEDGMENTS

The author would like to express his thanks and appreciation to the many colleagues within Lloyd's Register of Shipping who have given assistance during the preparation of this paper.

8 NOMENCLATURE

Upper Case

A	Section area
A_E/A_o	Expanded area ratio
B_L	Number of blades
C	Section chord length
C_A	Section area coefficient
C_P	Section pressure coefficient
C_Z	Section tension modulus coefficient
D	Propeller diameter
F_C	Centrifugal Force
J	Advance coefficient
K_Q	Non-dimensional torque coefficient $\left(= \frac{Q}{\rho n^2 D^5}\right)$
K_T	Non-dimensional thrust coefficient $\left(= \frac{T}{\rho n^2 D^4}\right)$
L	Centrifugal lever
M	Blade mass
N	Number of cycles
P_s	Shaft Power
Q	Propeller torque
R	Propeller tip radius
T	Propeller thrust
V	Ship speed
V_a	Propeller speed of advance
V_x	Axial component of ship speed
W	Relative velocity
Z	Section tension modulus

Lower Case

a	Thrust moment arm
a_c	Crack length
b	Torque force moment arm
c	Material constant
k	Stress intensity factor
m	Material constant
n	Propeller rotational speed
p_o	Stress section pitch
q	Harmonic order
r	Propeller radius
r_o	Radius of stress section
t	Section thickness
t_m	Section maximum thickness
x	Non-dimensional propeller radius or length along section chord
x_c	Non-dimensional radius of blade centroid
x_o	Non-dimensional radius of stress section
w	Taylor wake fraction

Greek Letters

ε	Blade surface strain
η_m	Mechanical efficiency of shafting and gearbox
η_p	Propeller efficiency
θ	Section pitch angle
ρ	Density of water
ρ_m	Density of propeller material
σ	Total section stress
σ_{CBM}	Stress due to centrifugal bending moment
σ_{CF}	Stress due to centrifugal force
σ_Q	Stress due to propeller torque
σ_T	Stress due to propeller thrust
$\sigma_\perp$	Stress due to out of plane components
ϕ	Angular position of propeller blade in disc
ω	Angular velocity

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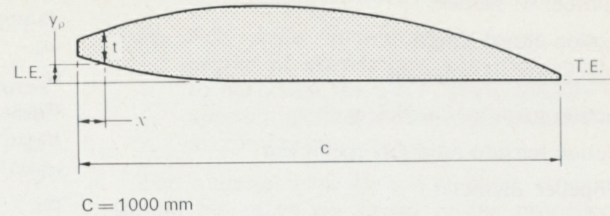
APPENDIX

CALCULATION OF THE MAXIMUM TENSILE STRESS ACTING ON A HELICAL SECTION OF A PROPELLER BLADE BY THE CANTILEVER BEAM METHOD

(1) STRESS BASIS

P_s	10820kW
RPM	140
V	18.7 knots
w	0.26
D	4900 mm
x_o	0.25
x_c	0.51
p_o	5000 mm
A_E/A_O	0.73
ρ_m	7600 kg/m^3
L	80 mm
B_L	4
η_m	0.98
η_p	0.55
a	0.7R
b	0.66R

(2) STRESS SECTION DATA



$r_o = x_o\ R = 0{,}25 \times \left(\frac{4900}{2}\right) = 612{,}5$ mm

C = 1000 mm $\qquad r_o = x_o\ R = 0.25 \times \left(\frac{4900}{2}\right)$

$= 612.5$ mm

x	0	55	110	220	330	497	665	832	1000	mm
y_p	55.0	39.0	25.0	6.5	0	0	0	0	0	mm
t	30.0	92.5	143.5	211.0	238.5	226.5	187.5	114.0	15.0	mm

(3) INTERPOLATED SECTION DATA

x	0	100	200	300	400	500	600	700	800	900	1000	mm
y_p	55.0	26.0	10	1	0	0	0	0	0	0	0	mm
t	30	136	195	232	236	226	205	173	128	73	15	mm

Chordal increment $\Delta C = \frac{C}{10} = 100$ mm

(4) EVALUATION OF SECTION PROPERTIES

COLUMN	1	2	3	4	5	6	7	8	9
ORDINATE	x	y_p	t	Simpson's Mult.	t $\times$S.M.	$(2y_p+t)t$	$(2y_p+t)t$ $\times$S.M.	$[3y_p(y_p+t)+t^2]t$	$[3y_p(y_p+t)+t^2]t$ $\times$S.M.
1	0	55	30	$\frac{1}{2}$	15	4200	2100	447750	223875
2	100	26	136	2	272	25568	51136	4233952	8467904
3	200	10	195	1	195	41925	41925	8614125	8614125
4	300	1	232	2	464	54288	108576	12649336	25298672
5	400	0	236	1	236	55696	55696	13144256	13144256
6	500	0	226	2	452	51076	102152	11543176	23086352
7	600	0	205	1	205	42025	42025	8615125	8615125
8	700	0	173	2	346	29929	59858	5177717	10355434
9	800	0	128	1	128	16384	16384	2097152	2097152
10	900	0	73	2	146	5329	10658	389017	778034
11	1000	0	15	$\frac{1}{2}$	7	225	112	3375	1687
TOTAL	—	—	—	—	2466	—	490622	—	1006826616

$$A = \int_o^c t\ dc = \frac{2 \times \sum \text{Col. } 5 \times \Delta C}{3} = \frac{2 \times 2466 \times 100}{3} = \underline{\underline{164400 \text{ mm}^2}}$$

$$\int_o^c (2y_p + t)\ t\ dc = \frac{2 \times \sum \text{Col. } 7 \times \Delta C}{3} = \frac{2 \times 490622 \times 100}{3} = 32708133 \text{ mm}^3$$

$$\int_o^c \left[3y_p(y_p+t)+t^2\right] t\, dc = \frac{2\times\sum \text{Col. } 9\times\Delta C}{3}$$

$$= \frac{2\times 1006826616\times 100}{3} = 6712177733 \text{ mm}^4$$

From equation (3.4)

$$Z = \frac{2 \times 6712177733 \times 164400}{3 \times 32708133} - \tfrac{1}{2} \times 32708133 = \underline{\underline{6137424 \text{ mm}^3}}$$

---

(5) **BLADE CENTRIFUGAL FORCE**

i) Calculate blade mass by

either

Evaluating Cols. (1) – (5) of the previous step for each defined helical section, thereby, obtaining the radial distribution of section area (A). The blade mass (M) is then calculated from

$$M = \rho_m \int_{r_o}^{R} A\, dr$$

N.B. (The position of the blade centroid (x_c) can also be calculated in an analagous way as shown in FIG. 7)

or

by use of approximation

$$M \simeq 0.75 \times \text{mean thickness} \times \left(\frac{\text{Total surface area}}{\text{No. of blades}}\right) \times \text{density}$$

viz. $M \simeq 0.75 \times 0.110 \times \left(\frac{0.73 \times \pi\, (4.90)^2}{4 \times 4}\right) \times 7600 \text{ kg}$

$M \simeq 2158 \text{ kg}$

ii) Centrifugal force is given by

$$F_c = 2\pi^2 M x_c D\, n^2$$

$$F_c = 2\pi^2 \times 2158 \times 0.51 \times 4.90 \times \left(\frac{140}{60}\right)^2 \text{ N}$$

i.e. $F_c = 580 \text{ kN}$

(6) CALCULATION OF SECTION MAXIMUM TENSILE STRESS

$$\text{Section pitch angle} \quad \theta = \tan^{-1}\left(\frac{p_o}{\pi x_o D}\right)$$

$$= \tan^{-1}\left(\frac{5000}{\pi \times 0.25 \times 4900}\right) = 52.41^\circ$$

$$\text{Propeller speed of advance} \quad V_a = V(1-w)$$

$$= 18.7 \times (1-0.26) = 13.8 \text{ knots}$$

$$= 13.8 \times 0.515 = 7.10 \text{ m/s}$$

i) Component due to propeller thrust:

$$\sigma_T = \frac{P_s \times \eta_m \times \eta_p \times (a-r_o) \times \cos\theta}{V_a \times B_L \times Z}$$

$$= \frac{(10820 \times 10^3) \times 0.98 \times 0.55 \times (0.7-0.25) \times 2450 \times \cos(52.41) \times 10^6}{7.10 \times 4 \times 6137424} = 22.50 \text{ MPa}$$

ii) Component due to propeller torque:

$$\sigma_Q = \frac{P_s \times \eta_m \times (b-r_o) \times \sin\theta}{2\pi \times n \times b \times B_L \times Z}$$

$$= \frac{(10820 \times 10^3) \times 0.98 \times (0.66-0.25) \times \sin(52.41) \times 10^9}{2\pi \times \left(\frac{140}{60}\right) \times 0.66 \times 4 \times 6137424} = 14.50 \text{ MPa}$$

iii) Component due to centrifugal bending moment:

$$\sigma_{CBM} = \frac{F_c \times L}{Z} = \frac{580000 \times 80 \times 10^6}{6137424} = 7.56 \text{ MPa}$$

iv) Component due to centrifugal force:

$$\sigma_{CF} = \frac{F_c}{A} \times \frac{580000}{164400} = 3.53 \text{ MPa}$$

TOTAL 48.09 MPa

Maximum Tensile Stress Acting on Section (σ) = 48.09 MPa

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Lloyd's Register Technical Association

Discussion

on the subject of

CRUDE OIL WASHING

following the Informal Meeting held during the Session 1980-81

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Any opinions expressed and statements made in this discussion paper are those of the individuals.

Hon. Sec. S. M. Wehrle
71 Fenchurch Street, London, EC3M 4BS

Discussion on the subject of

CRUDE OIL WASHING

following the Informal Meeting held during the Session 1980-81

FOREWORD

During February 1981, an informal meeting of the Technical Association was held in the Committee Luncheon Room at Headquarters, during which Mr S. C. W. Gresham, the National Safety Officer for the United Kingdom, chaired a panel discussion on the subject of Crude Oil Washing. Supporting Mr Gresham, the other panel members were Mr J. R. G. Smith from the International Conventions Department, and Mr R. Gardiner and Mr B. W. Oxford from the Machinery Design Appraisal and Plan Approval Department.

When opening the meeting the President of the Technical Association, Dr R. A. Goodman, asked participants in the discussion to subsequently pass their names to the Secretary, in order that their contributions might be included in this discussion paper for circulation to all the Surveyors, so that those unable to attend the meeting, and in particular our colleagues abroad, would be able to benefit from the discussion.

INTRODUCTION

By Mr S. C. W. Gresham:

This is a subject which has received a certain amount of publicity of late and so I imagine that a number of people here tonight know rather more about it than they did just a few months ago. However, one can read a great deal about a process and still not comprehend it so well as one does after seeing the job done; whilst the ideal, of course, is actually to take part in the operation. We can't arrange for all to take part—and not everyone would want to do so—but it was thought that you may find it of interest to see a couple of the films that we use on the COW training course at Crawley, and afterwards to take part in a discussion session in which we hope that your questions or comments may be dealt with by the specialists in their particular subjects who are present on the panel tonight—or perhaps, even in the body of the kirk—since there are a number of specialists in their own right who are not sitting here with the panel.

If I may just set the scene. . . . When we suffer a VLCC catastrophe, such as the one we had quite recently with the *Amoco Cadiz*, people became very much aware of the pollution on their doorsteps—the beaches submerged in a black oil film, the seabirds dying in their thousands, and the seafood beds of oysters and mussels killed off; the effect on tourism alone must create despair in the minds of all those seaside business people who see their living disappear—for who knows how long?

What people do not so readily think about is the slow death that has been coming to marine life all over the world for an appreciable number of years, caused by the oil pumped into the sea with the ballast water of innumerable tankers; see Fig. 1. How long is it, for example, since you first began to be aware of the black globules in the sand when you went for a day on the beach, and found that a pleasant swim had to be followed by a long session of foot cleaning—probably with the help of butter used for the sandwiches?

Nations became aware of the problem, and the 1973 International Convention for the Prevention of Pollution from Ships laid the basis for tank cleaning with the use of slop tanks and the retention on board of oil residues. It was, however, general practice to use sea water for the washing of the tanks and there were appreciable disadvantages in this

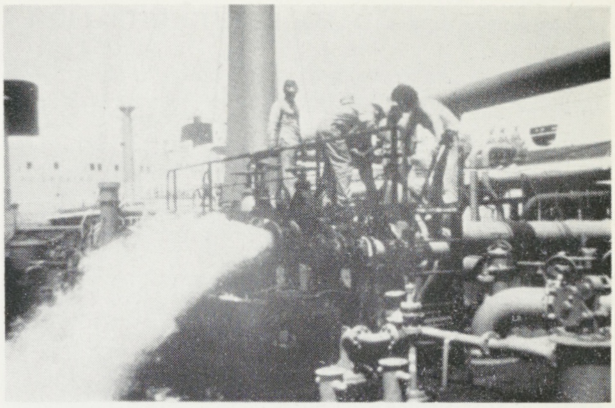

FIG. 1

Discharge of ballast from deck manifold

system, especially when the water was used at its own natural temperature. It did not, for instance, prevent the accumulation of sludge, and the amount of 'dead' freight in a VLCC could be in excess of 2000 tons. It contributed to corrosion inside the tanks and there was, inevitably, a certain amount of sea water in the cargo discharge.

Investigations had been going on for several years to find a safe, practical and economical cleaning agent. It was well known that hydrocarbon solvents are exceptional cleaning agents, but laboratory and on-board tests had to establish the way in which the crude oil cargoes themselves could be used to clean the tanks in which they were carried. Major tanker accidents in 1976 drew attention to the dangers of static electrical discharges associated with a mix of liquids—when using water washing, and as a result it was required that washing should only take place in an inert atmosphere—that is to say, in an atmosphere which did not contain enough oxygen to support combustion. So, by 1978, when American initiative brought about another International Conference on Tanker Safety and Pollution Prevention the value of crude oil washing was already appreciated, and rules were adopted and formulated as a Protocol relating to the 1973 Convention.

Broadly, existing tankers of 40 000 tons deadweight and above have the alternatives of segregated ballast tanks, dedicated clean ballast tanks or tank cleaning by crude oil washing. New crude oil tankers of 20 000 tons deadweight and above must have crude oil washing. It is also a requirement that an inert gas system is fitted in association with the crude oil washing equipment.

So much for a very brief introduction to the IMCO approach to the problem. It is one thing to lay down requirements, and another to see that they are carried out. This latter responsibility was placed in the hands of the Administrations of the countries in which vessels are registered and, of course, the problem of the work forces necessary to handle the many facets of the job became apparent. It was evident that there was a new field of operations opening up and proposals for LR involvement were put forward to our Management, as a result of which Mr F. H. Atkinson was empowered to chair a small Working Group drawn from involved departments, to ensure that we were ready with the necessary expertise and organization when the time came.

Now, so far as the Working Group was concerned the composition thereof was self-evident—International Conventions Department—without doubt. If crude oil washing was to take place it could only be in an inert atmosphere, and so our Engineering Departments were concerned not only with the inert gas system but with the pumping and piping concerned in new and retrofit installations; see Fig. 2.

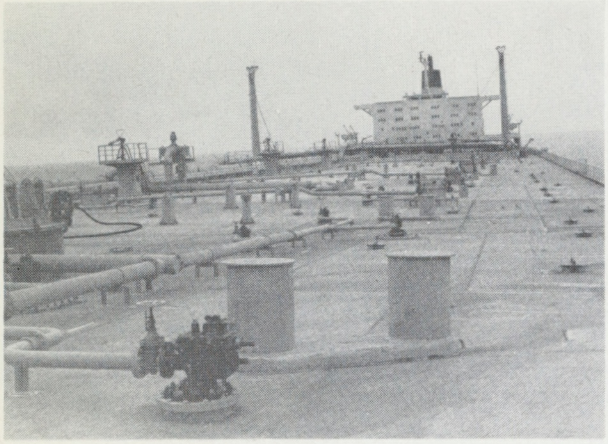

FIG. 2

Layout of piping to deck mounted washing machines

Monitoring instrumentation was clearly the concern of our Control Engineering Department, and the need for IMCO liaison was obvious. The essential task of the whole thing, of course, is the washing of the tanks, that is to say the optimum positioning of the washing machines, having regard to the structure within the tanks and the effective length of the jets—the latter obviously dependent on pressure and nozzle diameter, see Fig. 3, and this aspect of the work was to be undertaken within the Hull Structures Department. Finally, of course, the proof of the pudding is in the eating, and it lies with the field force to determine that the design work has resulted in clean tanks and an acceptable limit of oil in the ballast water.

The formation of this Working Group took place over two years ago, and as Safety Officer I rapidly became aware of the dark whisperings of Surveyors being expected to go into the cargo tanks after discharge of the crude oil just to see if they were clean or not—what sort of work was that for a naval architect or a marine engineer? At an early stage I was invited to join the deliberations, and as I became more interested I was more and more deeply involved until we reached the point at which I was asked if I was prepared to act as Lead Surveyor—and, really, what choice did I have? How can a Safety Officer formulate safety precautions unless he is fully aware of the problems involved? And that meant, of course, that I had to actually do the job—and, moreover, to do it on a number of ships. I have learned a great deal—not least that it is, indeed, fascinating work for a Surveyor in the field; see Fig. 4.

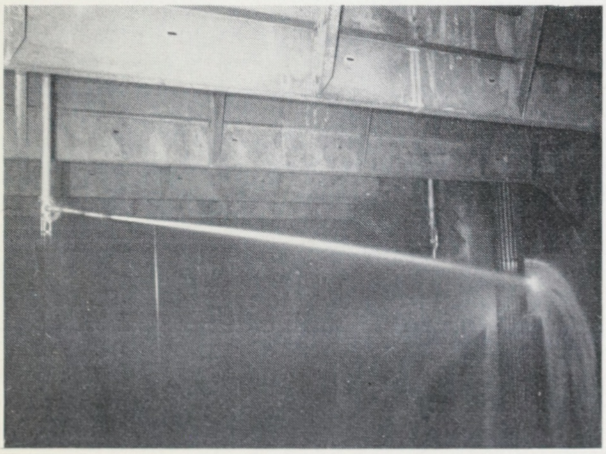

FIG. 3

Tank-washing machine in simulated operation using water

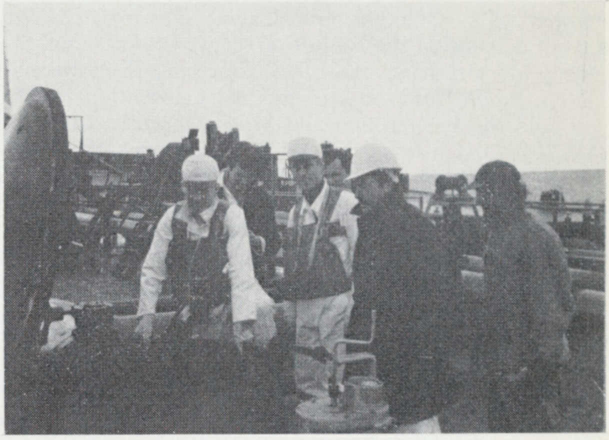

FIG. 4

Surveyors about to commence an in-tank cleanliness survey

Now I hope that this small introduction has explained to you—not how we do the job, but how we came to be involved. Any explanations necessary I shall leave to the experts, but at this point I commend you to the films after which you will have a much better idea of the principle involved.

EDITORIAL NOTE

At this point the two films were shown:

'Cleaner Tankers—Cleaner Seas'

and

'Inert Gas Systems'.

By Mr J. R. G. Smith:

As Mr Gresham has already said, crude oil washing was accepted as a means of preventing operational pollution at sea, during the International Conference of Tanker Safety and Pollution Prevention at IMCO in 1978, having previously been used by some of the major tanker operators as a means of increasing cargo out-turn. A brief explanation of the background to this event may be useful at this point.

For many years most of the world's tanker operators have used the load on top procedure as a means of preventing the overboard discharge of dirty ballast from cargo tanks. Briefly, the procedure is as follows: during or after cargo oil discharge, departure ballast is introduced into dirty cargo tanks. This ballast is allowed to settle during the first few days of the return voyage to the loading port until the free oil and water have separated into an oil layer on the top, then a layer of oil and water emulsion, with clean water ballast below. The oil/water interface is located by use of an oil/water interface detector and the clean ballast pumped overboard. The remaining oil and oil/water mix is then transferred to the slop tank. The natural oil and water separation process

again takes place and the settled clean ballast pumped overboard. Many tanker operators supplement this process by water washing the cargo tanks. It is well known now, of course, that if the tanks are not inert such water washing can produce an electro-static charge which, if released into an explosive atmosphere, can have disastrous consequences. By the continual and systematic application of this natural process of oil/water separation, the tanker arrives at the loading port with clean arrival ballast, the free oil having been collected in the slop tank or tanks. This arrival ballast is clean enough to be discharged into the loading port harbour. Cargo oil is then loaded into the cargo tanks and also into the slop tank or tanks on top of the oil already deposited there during the voyage. Hence the term 'load on top'.

One of the objectives of MARPOL 73 was to improve on this method, and so requirements for segregated ballast tanks were introduced for new oil tankers of 70 000 tons deadweight and above. These tanks were to be used for water ballast only with piping systems completely separate from the cargo oil system, thus avoiding oil/water mixtures entirely. Additional heavy weather ballast introduced into dirty oil tanks would still require to be separated by the load on top procedure.

At the 1978 International Conference, a proposal was made to make segregated ballast a requirement for existing ships as well as new ships and to reduce the deadweight limit to below 70 000 tons. There was, of course, strong opposition to this proposal insofar as it affected existing ships. Additionally, however, it was then required for new ships also, in addition to segregated ballast. It should be noted that whenever a crude oil washing system is fitted, an inert gas system must also be provided.

Requirements had therefore to be stipulated for the design, operation and control of crude oil washing systems such that after a cargo tank had been washed as specified and ballast water introduced into the tank, the oil content of the effluent in that ballast water would not exceed 15 ppm, this being the definition of clean ballast. It is therefore not surprising that the resulting requirements are complex. These requirements can be summarized briefly as follows:—

1. Tank washing machines are to be of a design acceptable to the Administration. The Society has specific requirements for the approval of machines, if required, but will consider acceptance of Certificates issued by National Administrations.

2. The number and location of machines are to be ascertained at the plan stage by ensuring that stipulated minimum shadow areas in each tank are not exceeded. Shadow areas are those parts of the tank not washed by direct impingement.

3. The crude oil washing, pumping and piping and the stripping system are to be in accordance with stated criteria.

4. Surveys after crude oil washing are required as follows:—
   (i) In-tank survey for confirmation of cleanliness.
   (ii) Measurement of oil content on top of departure ballast.
   (iii) Measurement of oil effluent in arrival ballast.

5. Ships' personnel must be qualified for the task of crude oil washing.

6. Operation of the crude oil washing system is to be in accordance with stated criteria.

7. An Operations and Equipment Manual, in accordance with stated criteria, is to be approved.

This work is handled by the Society as follows:

1. HULL STRUCTURES (Oil, Gas and Chemical Carriers Group)
   Approval of shadow area diagrams to establish the number and location of approved tank washing machines.

2. MDAPAD (Pumping and Piping)
   Approval of piping plans.

3. CONTROL ENGINEERING
   Approval of oil discharge monitoring and control systems fitted to measure the oil effluent in the arrival ballast.

4. OUTPORT SURVEYORS
   (i) Examination of the installation on board and preparation of a report to ICD/Pollution.
   (ii) Measurement of oil effluent in arrival ballast and preparation of a report to ICD/Pollution.

5. SURVEYORS SPECIALLY TRAINED IN CRUDE OIL WASHING
   (i) In-tank survey for cleanliness.
   (ii) Measurement of oil on top of departure ballast.

6. ICD/POLLUTION
   (i) Co-ordination of all the above work and liaison, if necessary, with the Administration concerned.
   (ii) Examination of Surveyor's reports.
   (iii) Approval of the Operations and Equipment Manual.
   (iv) Issue of appropriate documentation on satisfactory completion of all work.

ICD/Pollution has also prepared the following documents for use by Surveyors and Clients, both of which have been widely distributed:

1. Lloyd's Register Procedure for Crude Oil Washing Installations and Associated Inert Gas Systems.
2. Construction and Equipment Requirements of the 1978 Protocol Relating to the International Convention for the Prevention of Pollution from Ships, 1973.

The first document outlines the procedure to be followed regarding plan approval and surveys and includes the Society's safety requirements for cleanliness surveys mentioned earlier by Mr Gresham.

The second document, recognizing the complexity of the Pollution Prevention requirements of MARPOL 73 as modified and expanded by the Protocol of 1978, summarized all the construction and equipment requirements of MARPOL 73/78 (not just crude oil washing) in five guidance tables. Each guidance table relates to a specific ship type and size of ship. The requirements are also dependent on the size of the ship, there being three distinct age groups. Each guidance table shows the requirement for the three different age groups.

The co-ordination and reporting system is based on these two documents.

CONTRIBUTIONS

From Mr J. S. C. Bloomfield:

As shown by the first film, two benefits of crude oil washing became apparent. Firstly, less pollution of our seas because vessels are better able to strip their tanks with the aid of crude oil washing systems. A good mix to the cargo oil reduces the separation of waxy substances particularly at the end of discharge and thereby decreases the heel of oil remaining onboard and the amount of oil finding its way back to the sea via the ballast water.

Secondly, each vessel arrives at the loading port with cleaner slop free tanks and is able to load more cargo. In a large vessel the amount of deadweight involved could be of the order of 2000 tons.

The second film showing the use of inert gas systems, essential to reduce the free oxygen in the tanks, brings me to the first question.

Since the introduction of crude oil washing, with its attendant requirement of having an efficient inert gas system, has a reduction in ship loss by explosion or fire in the cargo areas been traceable? Inert gas systems are not new, but more vessels are having them fitted and through tank cleanliness surveys, their inspection and operation carefully checked.

My second question concerns oily water monitors. The introduction of oily water discharge monitors appears very slow; IMCO allows a three year delay time for fitting them after the date of entry in force of the convention for existing tankers, and the convention is not signed yet. What problems exist to delay the fitting of these monitors?

From Mr J. Crawford:

First I would thank the panel for a very enjoyable and instructive evening.

Having entered a cargo oil tank that had been recently subject to crude oil washing (though not for Survey purposes), I can vouch for the cleanliness of the bulkheads, however I did find the internal ladder ways and gratings to be very slippy and one had to be very careful in order to avoid skidding and losing grip of the handrails.

Could the panel give any indication as to whether this is a common finding, and was this possibly due to the roundness of the handrails not being conducive to direct impact of the crude oil jet streams?

Regarding the IMCO requirement for isolating the *Butterworth* heater during crude oil washing procedures, I would prefer to see this complied with by using an interlocked valve arrangement rather than blocks or double shut-off valves, since I consider there is always a possibility of human error where locking of valves is indicated. Could the panel give their views regarding any preferred system of isolation in this respect?

Crude oil washing, segregated and dedicated clean ballast have now become standard phraseology in MDAPAD and there are various interpretations of the requirements in relation to piping systems for these services. Would it be possible for the panel to give some indication, preferably in the way of sketches/diagrams, of acceptable piping arrangements?

Regarding inert gas systems the Rules require provision for isolating the individual cargo tanks from the inert gas main and reference has been made to possible acceptable arrangements for complying with these requirements, i.e. isolating valves and/or spade type blanks. Whilst the first of these, isolators (i.e. shut-off valves) probably gives no cause for concern, the latter (spade blanks) can, if not inserted properly, that is with the spade handle/extension vertically upwards, result in the tank hatch being capable of being closed with the spade in place.

Accordingly it behoves the Surveyor to satisfy himself that the spade blank is:—

(a) located properly, and

(b) the spade handle/extension is of sufficient length that the hatch cover cannot be closed with the spade in place.

Finally, having regard to the multiplicity of IMCO regulations at present to hand could the panel advise as to which of these regulations are at present in force and which are pending/awaiting ratification?

It is noted that IMCO Regulations in addition to indicating minimum acceptable requirements has also become involved in the design features of such systems. Does the panel consider that the above organization, however well intended, has become too involved in the detail application of the various requirements?

From Mr R. M. Hobson:

The panel has ably demonstrated the contribution that crude oil washing procedures are making towards cleaner seas and it has been most enlightening to have Mr Gresham confirm, from his own first hand experience, just how efficient the system is proving to be.

This leads me into my question which concerns the philosophy adopted by IMCO when the various regulations were formulated.

It is dangerous to generalize when discussing the MARPOL regulations but at the risk of over-simplification I will describe the regulations as referring to three age groups of ships.

The actual requirements are summarized in an excellent manner in the Society's publication *Construction and Equipment Requirements of the 1978 Protocol Relating to the International Convention for the Prevention of Pollution from Ships, 1973.*

Group 1

Existing tankers contracted before the MARPOL 1973 regulations became mandatory. That is to say, those contracted before the end of December 1975.

Such ships can opt for segregated ballast tanks or crude oil washing and for a limited period they have a third option—dedicated clean ballast tanks.

I believe most owners are, or will, opt for the COW alternative since the SBT or CBT options will result in a considerable loss of usable cargo deadweight.

Group 2

Next, one must consider the category of tanker such as affected mainly by the MARPOL 1973 regulations. Those over 70 000 deadweight tons contracted after the end of December 1975 but before the MARPOL 1978 Regulations became effective.

Such ships are only required to have segregated ballast tanks.

Group 3

Finally new tankers, being such ships as have been contracted since June 1 1979.

These tankers must have segregated ballast tanks *and* crude oil washing.

It has been illustrated already by the panel, that a good deal of pollution in the past came from discharging ballast water which had been carried in unwashed cargo tanks (departure ballast) and accordingly the SBT and/or COW

requirements will largely eliminate this source of pollution. However, it has always been common practice to wash about one-quarter of all cargo tanks on each voyage for sludge control purposes and this source of contamination has been a far greater cause of pollution than the discharge of departure ballast into the sea.

For those ships using COW procedures, this source of pollution will be very much reduced, but ships falling within the second category mentioned above will presumably have to process the washings and remains of cargo from 25 per cent of their cargo tanks every voyage—furthermore such ships will still be in service five or 10 years from now.

Does the panel not think that IMCO should have insisted on such ships also adopting the crude oil washing procedures and what was the rationale behind the omission of this requirement?

From Mr A. J. Williams:

This has been a very interesting evening and the speakers are to be congratulated on the lucid and absorbing way they have presented the subject.

There may be an impression, however, that a number of experts sat down at IMCO with the noblest of thoughts and proceeded dispassionately to draw up an agreement in the best interests of all parties. The reality appears to have been somewhat different and the lobbying of different groups, each seeking to advance their own interests, seems at times to have been intensive. The result is a compromise but, we must hope, a workable one.

There is one point which perhaps the speakers could clarify. Where a ship has segregated ballast tanks, is there any requirement for pollution control measures in the cargo oil tanks, other than the limitation on the discharge of dirty ballast? Obviously these tanks have to be cleaned for operational reasons as well as for survey and repair. Is it possible for an Owner having provided, at considerable cost, a segregated ballast tank system then to economise by not installing COW or even 'load on top' in the cargo oil tanks? If so, it would seem there could be a more difficult cleaning problem than at present, particularly on crude trades where there may be a rapid build up of sludge in the tanks.

From Mr D. Milton:

Would the panel give an indication of the overall work load anticipated by the Society for existing ships as a result of the IMCO Regulations, and also a breakdown of the average time spent by different departments on certifying work. The time spent by Hull Structures on certifying shadow diagrams for an average ship is of the order of 15 man days.

Since shadow area diagrams are a design tool to enable sufficient washing guns to be provided in a tank, can the panel indicate what correlation there is between the diagrams and the actual surveys, bearing in mind that if the shadow diagrams criteria result in too many guns being fitted, that Owners will be pressing to have the criteria relaxed?

Would the panel confirm that the Society can turn down a washing gun arrangement based on a survey, or does the tank have to fail the oil content tests for clean and dirty ballast water as well?

From Mr T. Sullivan:

Has consideration been given to the possibility of a Surveyor examining a cargo tank after crude oil washing, being presented with the problem of making a decision on the condition of the structure of this tank?—bearing in mind:

(a) the Surveyor must be fit, reasonably young, and consequently relatively inexperienced in structural surveys.

(b) the structures will be exposed as it has never been exposed since the ship was built.

From Mr J. M. Burley:

After the initial installation and cleanliness surveys, what will be the periodical survey requirements?

REPLIES

To Mr Bloomfield:

It is impossible to quote statistics indicating that the increased use of inert gas systems has reduced ship losses due to explosions or fire. In fact, it is regrettable that losses due to explosion are continuing, and within the last two years we have had several instances of loss of large tankers attributable to this cause.

These explosions have usually occurred during ballast voyages and whatever evidence has been available would seem to indicate that either the inert gas systems had not been in use at the time, or may have been improperly used.

What we can say, without any doubt, is that if the inert gas system is properly used and all necessary precautions are observed with regard to the oxygen content of the inert gas and the associated safeguards to prevent passage of hydrocarbon gases to hazardous areas then the risk of ship loss due to explosion is very effectively reduced.

It is true that inert gas systems are now widely installed, and that their use is mandatory when crude oil washing is in progress, but it is essential that the personnel operating the systems should be experienced people who are concerned with safe operation, and who understand the danger involved in failure to observe straightforward safety requirements. We are well aware, however, that human nature is such that often those who should be most concerned with their own safety, namely, the seafarers, are those who blithely ignore the simple checks that would eliminate the elements of risk.

The principle of the use of inert gas in the tanks is very simple in that it aims to ensure that there is insufficient oxygen to support combustion, no matter what the concentration of hydrocarbon gases may be. This is particularly important during the crude oil washing operation when not only is there the possibility of static discharge (though we seek to eliminate that by using 'dry' crude in the washing jets) but also there is a marked increase in the generation of hydrocarbon gas due to the fact that the crude oil is being fired through the washing machine nozzles under high pressure and sprayed around the tank by impingement on the steel structure. When one realises that the generation of gas is of the order of seven cubic metres of gas per minute per washing machine, and that the washing programme on a VLCC may involve perhaps 6000 machine minutes, then the need for protection against explosion risk is readily appreciated.

Before tanks are ventilated to provide internal access for inspection or maintenance they are purged by an inflow of inert gas forcing out hydrocarbon gas to the atmosphere until the volume of hydrocarbon gas left in the tanks is insufficient to produce an explosive level when mixed with air introduced as the inert gas, in turn, is forced into the atmosphere.

Whilst the Surveyor is present, i.e. during the initial cleanliness verification survey, his job will commence before cargo discharge with the checking of the inert gas system and the calibration of the oxygen analyser, together with analysis by a portable instrument of the actual oxygen content in the inert gas at a point near to the delivery to the tanks. Whilst he is present, then we feel sure that the danger of explosion should be non-existent. It is after our work is done, and the ship is in normal service, that the need is evident for responsibility amongst the people handling the everyday operations.

Summing up, then, the proper use of an inert gas system should eliminate the possibility of explosion—but the emphasis is on 'proper use'.

Further to Mr Bloomfield's final question 'what problems exist to delay the fitting of these monitors?', part of the difficulty has been in developing a 'test of performance' specification and in determining the extent to which any control has to be exercised and the extent of the information required to be continuously recorded. This refers in particular to MARPOL Regulation 15(3)(a) which requires a continuous record of the discharge in litres of oil per nautical mile and the total quantity discharged, or the oil content and rate of discharge. This problem has now been resolved in the publication of IMCO Resolution A.393(X) entitled 'Recommendation on International Performance and Test Specifications for Oily-Water Separating Equipment and Oil Content Meters'.

At one stage, it seemed as though a black box concept could be envisaged where everything would come into operation automatically. However, this was considered impractical and to some extent the operation of the monitor system must remain manual taking into account that, on some tankers, there may be as many as 12 points from which samples would require to be taken and monitored to prevent the discharge overboard of any oily effluent.

Further difficulties were also experienced in obtaining a monitor capable of monitoring the discharge of light refined products or white oil (see Regulation 15(6)); and also of marinising monitors which, although successful in land based conditions, were adversely affected by the salt laden atmosphere, ship's motion and vibrations when used on board ships.

Since the experts at IMCO have spent a considerable amount of time on this subject, it would be impracticable to go into greater detail here. It is perhaps sufficient to say that the requirements for oily water separators and monitoring equipment have been detailed in various IMCO documents, the latest of which is the Marine Environment Protection Committee Paper MEPC XIV/5. We also now receive in MDAPAD quite a number of cases where oil monitoring systems are submitted for approval in connection with Owner's requests for the Society to issue Statements of Compliance with the MARPOL Convention.

Regarding Mr Bloomfield's second question concerning oil content monitors, the allowance of a three year delay time after the date of entry into force of the Convention for existing tankers was not because of any technical difficulties foreseen at that time. Otherwise the same three year period would have been applied to new ships. It would appear that the reason was to give Owners of old tankers the commercial option of either fitting an oil content meter and its attendant oil discharge monitoring system to enable discharge of oily mixtures into the sea, or not doing so and therefore having to discharge to a shore reception facility. In this respect it should be noted that Regulation 9 of MARPOL 73/78 prohibits the discharge into the sea of oily water mixtures unless, *inter alia*, an oil discharge monitoring and control system is fitted. This applies to new and existing ships. The only alternative is to discharge to a shore reception facility. Regulation 12 of MARPOL 73/78 requires all Parties to the Convention to provide such facilities.

To Mr J. Crawford:

When one thinks of the hazards associated with tank entry it is natural, perhaps, to think immediately of the dangers involved with the presence of toxic gases or with the lack of oxygen. However, the experience of this inspection in a large number of tanks is that the danger of falling is by no means the least of our worries. Mr Crawford is absolutely right when he draws attention to the slippery condition of ladderways and gratings, and it is to minimise this danger that our Surveyors have been issued with safety boots having slip resistant soles and with light cotton gloves of what we call 'polka dot' design, that is, having the palms and fingers studded with small rubber dots to enable a maximum grip on the steel handrails.

Although the state of the ladders and walkways can vary, it is, in fact, quite common to find that they are more greasy than parts of the tank structure. In our view, this may be due to the fact that the steel structure is washed not only by the direct impingement of the jet but by the splash back effect of the jet being bounced around between bulkheads, webs, stringers, and brackets, whereas the ladders and walkways usually have the jets impinging briefly and then passing on through the spaces between rungs. This appears to be borne out by the fact that walkways composed of spaced metal rods are usually more greasy underfoot than those made of expanded metal platforms, which seem to get a better wash.

With regard to the use of the spade blanks in the inert gas supply lines those we have seen in use would be difficult to install other than with the handle vertically upwards, thereby preventing the hatch lid from being closed whilst the inert gas supply is blanked off; see Fig. 5. Having said that, we have heard of a case in which the handles were appreciably shortened by the crew in order to make them lighter to handle and easier to stow.

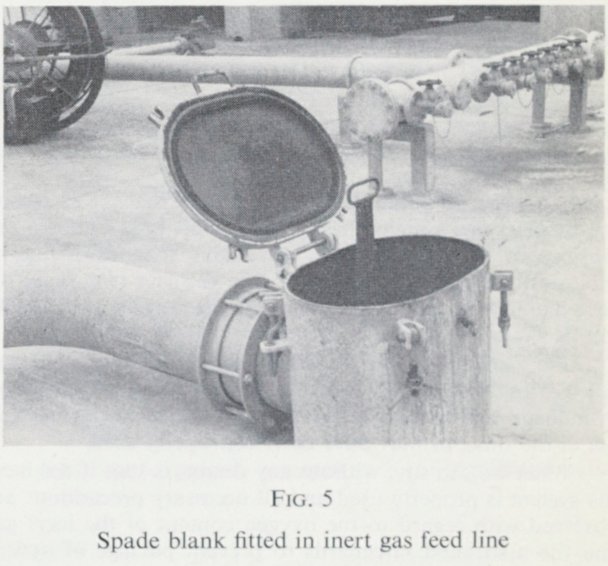

Fig. 5

Spade blank fitted in inert gas feed line

Concerning the IMCO Regulations at present in force they are, of course, of such number that apart from the original Printed Publications for the 1973 International Conference on Marine Pollution and the 1978 Protocol Relating to the International Convention for the Prevention of Pollution from Ships, 1973, there have been numerous amendments and interpretations issued such that it would be impossible to itemise them within the scope of this discussion.

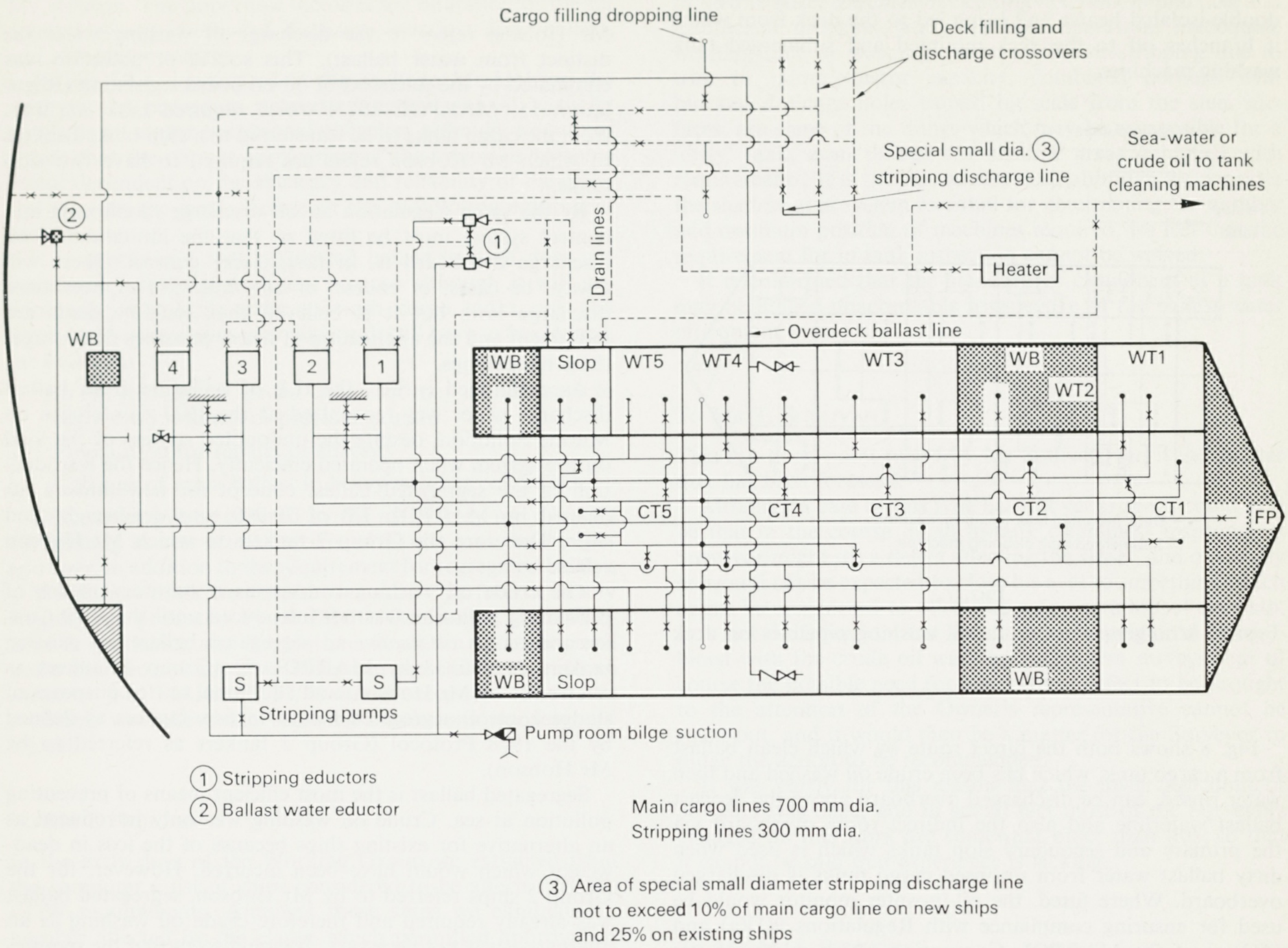

FIG. 6

Typical cargo pumping arrangement for 320 000 dwt tanker

Grey areas in interpretation still exist and they are to be resolved in discussion within IACS and within IMCO, so it is necessary for those directly concerned with the application of the legislation to keep closely in touch with the discussions taking place, and also, of course, with the unilateral application of allied legislation by individual countries.

It is difficult for a body such as IMCO to limit involvement in the application of requirements and the feeling of the Panel is that the degree of involvement is about right, leaving a certain amount of discussion on interpretation and application to the Administrations, or Classification Societies representing Administrations. A typical example would be the requirement for analysis of arrival ballast water to ensure that the oil content is within the defined limit. There are various ideas as to how, in the absence of an approved monitor, samples should be taken and analysed, and this is one subject of on-going discussion.

With regard to Mr Crawford's comments on the preferred method of isolating the so-called *Butterworth* heater, the relevant paragraph, i.e. 4.1.6 of Resolution A.446(XI), requires the heater to be effectively isolated during crude oil washing by double shut-off valves or by clearly identifiable blanks and in our approval experience these are the two most common methods of isolating the heater, although a portable spool piece arrangement would be equally acceptable. For a ship equipped with crude oil washing, the only time the heater would be put into use is either when water rinsing the tanks when required on existing ships or if the crude oil washing system is out of commission and the ship has reverted to water washing all the tanks until such time as the crude oil washing system is repaired. In either case, the preference these days seems to be to cold wash the tanks and as the new tankers come into service there will be even less cause to use the heater. In these circumstances, whilst no objection is seen to an interlocked valve system, it seems unlikely that any Owner will opt for other than the cheapest system.

Also, as requested by Mr Crawford, we are pleased to append below three sketches which relate in some measure to crude oil washing, segregated ballast tanks and to the use of an oil-in-water monitor in conjunction with a slop tank arrangement.

As indicated, Fig. 6 is a typical arrangement of the piping systems within the cargo area on board a 320 000 deadweight oil tanker and shows amongst other things, the cargo oil pumping arrangements, the crude oil washing supply line and double isolated heater, the segregated water ballast system, the overdeck filling of cargo oil tanks with sea water which may be considered as clean water ballast provided the cargo tank has been water rinsed after crude oil washing, and the small diameter stripping discharge line.

At first glance this seems a complicated plan and in order to appreciate the contents more easily it is best to see the various systems in different colours.

Fig. 7 shows the crude oil washing line by-passing the double-isolated heater and being led to the deck from which it branches off to the deck mounted and submerged tank washing machines.

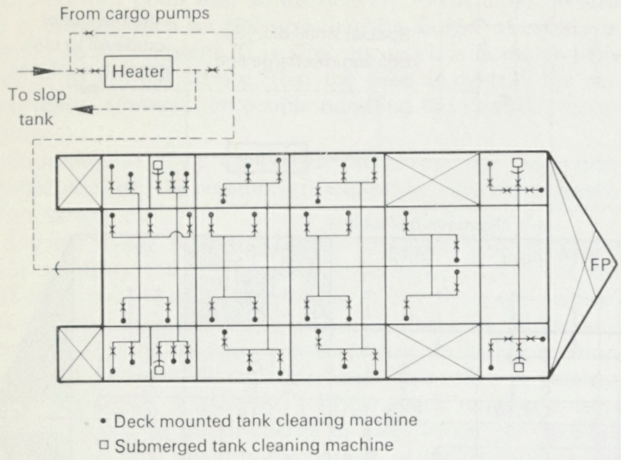

FIG. 7

Typical arrangement of crude oil washing pipelines on deck

Fig. 8 shows both the direct route by which clean ballast from a cargo tank, which has been crude oil washed and then water rinsed, can be discharged overboard above the deepest ballast waterline and also the indirect route overboard via the primary and secondary slop tanks which is used when dirty ballast water from unrinsed cargo tanks is discharged overboard. Where fitted, the oil-in-water monitor would be used for ensuring compliance with Regulations 9(1)(a) and 15(3)(a) of the MARPOL Convention which relates to the conditions and control of such overboard discharges.

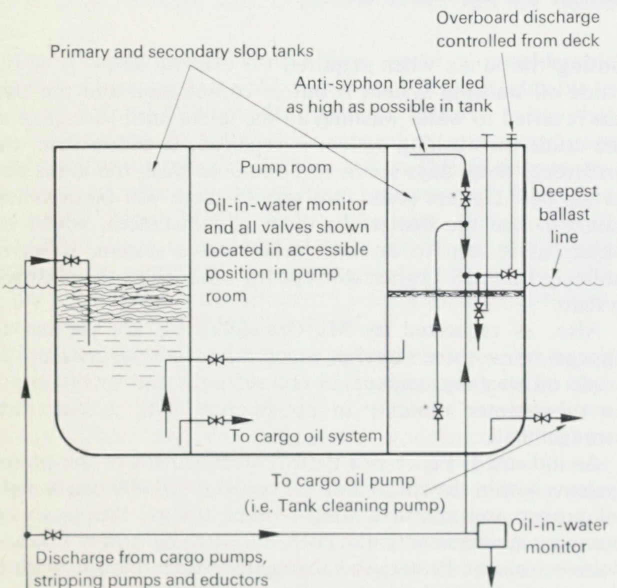

FIG. 8

Slop tank arrangement

TO MR HOBSON:

Mr Hobson refers to the discharge of washing water (as distinct from water ballast). This source of pollution was eliminated by the retention of oil on board legislation (Regulation 15, MARPOL 1973) which required tank washings from the cargo tanks to be transferred to a slop tank. Tankers to which Mr Hobson refers are required to have two slop tanks.

By the same Regulation an oil discharge monitoring and control system must be fitted so that the limitation of oil discharge overboard is, in fact, under control. There will always be cases, of course, of contravention of overboard discharge laws but it is believed that such incidents are infrequent and the application of heavy penalties discourages these happenings.

As mentioned earlier, the risk of pollution from ballast discharge water was recognized at the 1973 Conference on Marine Pollution, despite the undoubted success of the load on top system when operated efficiently. Hence the introduction of the segregated ballast concept for new tankers (as defined by MARPOL 73) of 70 000 tons deadweight and over. These are the Group 2 tankers to which Mr Hobson refers.

The crude oil washing concept as a statutory means of preventing pollution was not introduced until the 1978 Conference, as an *alternative* to segregated ballast for existing tankers as defined by MARPOL 73 (Group 1 tankers as referred to by Mr Hobson) and additional to (for purposes of sludge control) segregated ballast in new tankers as defined by the 1978 Protocol (Group 3 tankers as referred to by Mr Hobson).

Segregated ballast is the most efficient means of preventing pollution at sea. Crude oil washing was only introduced as an alternative for existing ships because of the loss in deadweight which would have been incurred. However, for the Group 2 ships referred to by Mr Hobson, segregated ballast was already required and therefore crude oil washing as an alternative was not necessary. It would seem that the requirements for crude oil washing on new tankers, as defined by the 1978 Protocol, in *addition* to segregated ballast was simply a price to be paid for acceptance of crude oil washing as an *alternative* to segregated ballast on existing tankers.

It is only since that time that the present considerable experience of crude oil washing as a pollution preventive has been gained. Even then it must be realised that it is not foolproof. Failure by the operating personnel to apply the procedures laid down in the approved Operations and Equipment Manual could result in dirty tanks and consequent pollution of the sea on subsequent discharge of ballast. The only foolproof method is to ensure that the ballast is never in contact with the oil cargo, i.e. segregated ballast.

Furthermore, the Group 2 ships referred to by Mr Hobson are required to have not only slop tanks but also oil content meters and oil discharge monitoring and control systems. Any overboard discharge is required to comply with Regulation 9. If this cannot be done, the oily mixture should be retained in the slop tanks for either load on top or discharge to a shore reception facility.

TO MR A. J. WILLIAMS:

Mr Williams may well have a point in his remark concerning the drawing up of the legislation on the present subject, but this could be a case of 'the end justifies the means'. No matter what reasons actually lie behind a decision to go for crude oil washing—and once the initial outlay has been written off the system has an undoubted economic attraction to Owners by virtue of its advantages of increased cargo and reduced corrosion, labour and other costs—the end result must be cleaner seas.

We think Mr Williams' query is dealt with by the reply to Mr Hobson. The important factor is the limitation of the oil content of any overboard discharge, not just dirty ballast, and it is under control.

As has been emphasized in the reply to Mr Hobson the load on top procedure properly practised should virtually eliminate oil tanker operational pollution, although we cannot ignore that the correct application of the system is to some extent dependent on the efficiency and reliability of the crew, and also on the same factors in the monitoring equipment provided.

It is appreciated that segregated ballast in itself does not completely solve the problem, because although it will undoubtedly reduce the need to wash cargo tanks one can think of several reasons why tanks will still have to be cleaned, for example:

1. In the carriage of special cargoes it may be necessary to remove all residues of previous crudes.
2. Preparation for repairs or survey.
3. Carriage of extra ballast in heavy weather conditions.

This aspect will be covered by the mandatory use of crude oil washing in new crude carriers of 20 000 tons deadweight and over, in addition to the requirement for segregated ballast.

We do not think we should ever expect perfection in any Regulations produced by an IMCO Conference. The problems in producing any Regulations at all are enormous and under the circumstances we believe in most cases they do an excellent job. MARPOL 73/78 is no exception. Given the problem, we believe the resulting regulations are fair and logical.

To Mr D. Milton:

In the early days of the Working Group we extracted from the computer a list of ships considered to be affected by the COW requirements. Amongst those ships we eliminated a number affected by the clause which permitted approval of one of a series of sister ships and it was recognized that a number of ships could also be eliminated due to age and scrapping (perhaps for economic reasons).

In round figures, we felt that 400 existing ships would require consideration, and of course, we knew that new ships would form an on-going exercise.

The time necessary for checking shadow diagrams within a tank will vary with the complication of the structure and the number and location of the machines, but two days per tank might reasonably represent Hull Structures time for approval of shadow diagrams. Plan approval in the Engineering Departments can usually be carried out in one day per ship. In the Pollution section of International Conventions Department, approval of an Operations and Equipment Manual may occupy three to five days whilst the co-ordination of certification work may vary between two and four days.

Since the final decision as to whether or not a tank is clean depends on the in-tank inspection, the general opinion of the field force carrying out these inspections is that provided the shadow area's design criteria are complied with, i.e. that 85 and 90 per cent of the vertical and horizontal areas, respectively, are washed by direct impingement, the tank should be clean. One must remember, however, that a number of factors affect the efficient cleaning of a tank in practice, and insufficient pressure, faulty machine operation, inadequate washing time or washing cycles, inefficient stripping due to trim or pump/eductor capacity, combined perhaps with blocked drainage holes caused by scale from the steel surfaces, are some of the things which may be responsible for a 'dirty' tank, even though the shadow areas complied with requirements. It is for this reason that, although we consider the shadow area system essential for determining the number and optimum position of machines required, we feel that the requirement for in-tank inspection cannot be waived.

It is confirmed that the standard of cleanliness of a tank may be judged unacceptable irrespective of the ballast water oil content tests.

To Mr T. Sullivan:

This is a good point raised by Mr Sullivan, but it is a matter that has been foreseen.

Although a case of this type has not yet arisen it could well be that in the course of an in-tank cleanliness inspection a Surveyor might see a defect affecting the vessel, and obviously he would not be expected to close his eyes to something which might be considered to affect the safe operation of the ship. It is not the intention that structural surveys should be combined with the crude oil washing cleanliness surveys, but of course the possible need for a structural defect to be brought to the attention of the Owner's representative cannot be ruled out, and it would then be a matter for the Surveyor to judge the action to be recommended.

It was partly for this reason that the lower age limit of 30 years was fixed, and in actual fact most of the Surveyors engaged on this work are somewhat older than this, so that it cannot be said that experience is lacking.

To Mr M. J. Burley:

In accordance with regulations under Annex 1 of the 1978 Protocol, periodical surveys at intervals specified by the Administration, but not exceeding five years, are to be held.

A minimum of one intermediate survey is to be held during the period of validity of the International Oil Pollution Prevention Certificate, and as this period will normally be five years, when one intermediate survey is held it is to be within six months either side of the half-way date, i.e. $2\frac{1}{2}$ years plus or minus six months.

Discussion in detail is going on in IACS where draft guidelines on Initial, Annual, Intermediate and Renewal Surveys are being considered by a Working Party.

It would be somewhat premature, therefore, to refer at this time to the survey requirements. We know, for instance, that the matter of in-tank inspection is under consideration but it will be necessary to wait for the outcome of the IACS deliberations before we can determine what form application of the periodical surveys will take.

It is also intended that our finalized guidelines be submitted to IMCO for consideration by the Marine Environmental Protection Committee.

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